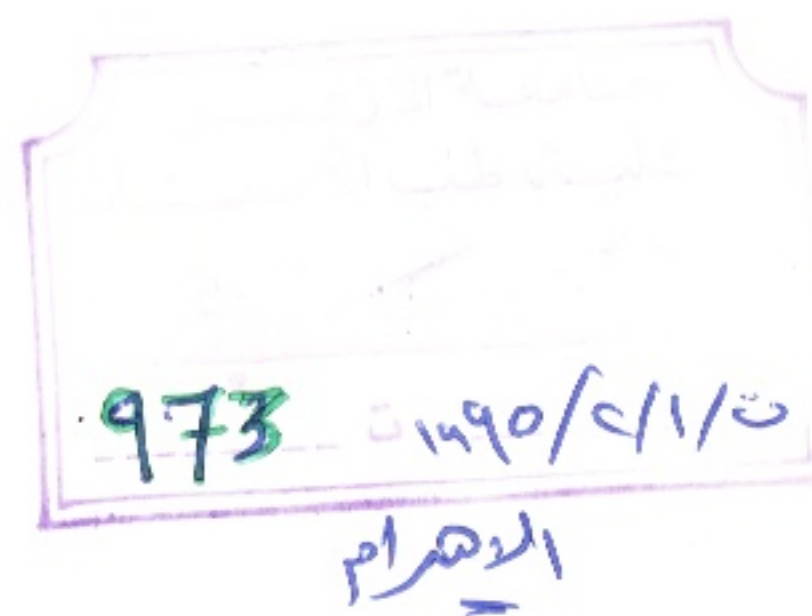


<http://dentalbooks-drbassam.blogspot.com>

Introduction to

Metal Ceramic Technology

W. Patrick Naylor, DDS, MPH, MS



٦١٧.٦٩٥

Na. I

Introduction to Metal Ceramic Technology



W. Patrick Naylor, DDS, MPH, MS

With contributions by:

James C. Kessler, DDS

Arlo H. King, CDT

DropBooks

<http://dentalbooks-drbassam.blogspot.com>

Quintessence Publishing Co, Inc
Chicago, London, Berlin, São Paulo, Tokyo, and Hong Kong

Contents

Chapter 1	Introduction	9	
	Historical perspective		
	The art and science of dental technology		
	Metal ceramic terminology		
	Components of the metal ceramic restoration		
Chapter 2	The Chemistry of Dental Porcelain	17	
	Terminology		
	Classification of dental porcelains		
	The chemical components of dental porcelain		
	Varieties of low-fusing porcelains		
	Requirements of a porcelain for bonding to metal		
	Nondiscoloring (nongreening) dental porcelains		
	Porcelain firing schedules		
Chapter 3	Casting Alloys for Bonding to Dental Porcelain	27	
	The chemistry of metal ceramic alloys		
	Classification of dental casting alloys		
	Description of metal ceramic alloys		
	Noble metal alloys		
	Base metal alloys		
	Other important features of metal ceramic alloys		
Chapter 4	Essentials of Metal Ceramic Substructure Design	43	
	Functions of the metal ceramic substructure		
	Principles of substructure design		
	Single-unit restorations		
	Fixed partial dentures		
	Designing the interproximal areas of substructures		
	Margin designs for metal ceramic restorations		
	Substructure design checklist		
Chapter 5	The Fundamentals of Spruing, Investing, and Casting	65	
	Spruing techniques		
	High-heat casting investments		
	Investing technique		
	Wax elimination (burnout) technique		
	Melting and casting techniques		
	The laws of casting		
	Analyzing casting failures		
Chapter 6	How Does Dental Porcelain Bond to Metal?	83	
	Mechanisms of porcelain-metal attachment		
	The oxidation (degassing) process		
	Postoxidation treatment		
	Porcelain-metal bond failures		
Chapter 7	Preparation of the Metal Substructure for Porcelain	93	
	Casting appraisal		
	Armamentarium		
	Metal finishing procedures		
	Finishing other types of single-unit restorations		
	Finishing a fixed partial denture		
	Soldering fixed partial dentures		
	Oxidizing the fixed partial denture		
Chapter 8	Applying Porcelain to the Metal Substructure	115	
	Instruments and equipment		

DropBooks

<http://dentalbooks-drbassam.blogspot.com>

Introduction

Historical perspective

Anyone who has ever attempted to chronicle the history of ceramic materials is certain to have discovered that the Chinese are credited with the development of porcelain as early as 1000 AD (Jones, 1985). Despite repeated attempts, European craftsmen were unsuccessful in their own efforts to unravel the secrets of Chinese ceramic technology. In fact, the best that German researchers could do was produce materials akin to Chinese stoneware. While this was an improvement over porous and crude earthenware, these early European ceramic products did not approach the quality, strength, and translucency of fine oriental porcelains.

In what Jones described as "an early example of industrial espionage," d'Entrecolles, a Jesuit priest, ingratiated himself with Chinese potters around 1717 in order to learn the coveted porcelain manufacturing process (Jones, 1985). Thanks to d'Entrecolles, it took less than 60 years for porcelain to become a material with an application in dentistry.

According to many historical accounts, dental porcelain was used first to fabricate complete dentures. After numerous refinements of the basic feldspar-quartz-kaolin composition and a few hundred years of trials and tribulations, the technology for the metal ceramic restoration eventually emerged in the 1950s. But the road to modern "ceramics," as we know it in dentistry today, was a long and treacherous stretch, often littered with disappointments and outright failures. Historical accounts have singled out and credited specific individuals with achieving certain milestones in ceramic technology, yet the evolutionary process reflected the combined talents of many inquiring minds and very determined researchers.

For example, in the late 18th century there lived a French apothecary by the name of Alexis Duchateau. There is evidence to indicate that Duchateau was edentulous and troubled by stained and odiferous ivory dentures, a condition probably quite common among the general population at that time (Jones,

1985). Armed with his skills as an apothecary, Duchateau attempted to make a pair of porcelain dentures for himself. Much to his dismay, those initial efforts were less than successful (Ring, 1985). It was not until he teamed up with the Parisian dentist Nicolas Dubois de Chemant that the two were able to construct complete dentures from a material they referred to as "mineral paste" (Ring, 1985). Satisfied with the improved fit of his new dentures, Duchateau returned to his apothecary shop. But de Chemant became intrigued by his experimentation and went on to reformulate the original "mineral paste." He focused his efforts on enhancing the color, dimensional stability, and attachment of the "mineral" teeth to the denture base.

De Chemant eventually patented the formulation and in 1788 published a pamphlet on his work. It was not until 1797 that his more definitive text, *A Dissertation on Artificial Teeth*, appeared in print. Not everyone hailed de Chemant's decision to patent his porcelain material. In fact, some of his contemporaries regarded his actions as nothing more than the theft of Duchateau's original invention (Jones, 1985). On the other hand, the work of Duchateau and de Chemant may have been preceded by another French dentist, Pierre Fauchard, the "father of modern dentistry" (Jones, 1985). Evidently, Fauchard and others had reported using what they referred to as "baked enamel" before 1760 and perhaps as early as 1728 (Jones, 1985).

Italian Giussepangelo Fonzi reportedly devised a method to mass produce individual porcelain denture teeth around 1808. Fonzi devised a technique for placing platinum pins in the back of the teeth so they could then be soldered to a metal denture base.

Accounts of when this technology made its way through Europe and across the Atlantic to the United States differ slightly among dental historians (Jones, 1985; Ring, 1985; Hagman, 1980a, 1980b). Apparently the French dentist Antoine Plantou introduced individual porcelain teeth to America around 1817

Table 1-1 Factors affecting esthetics in prosthodontics

Type of treatment	Level of control	Comments
Complete denture prosthodontics		
• Tooth form (mold)	Maximum	Wide selection
• Tooth color (shade)	"	Wide selection; can mix shades
• Gingival form	"	Can create natural contours; can modify at try-in
• Gingival characterization	"	Can use internal staining; can apply stains externally
• Dental materials	"	Many types of denture base acrylic resins available; can choose veined/nonveined acrylic resin; several shades to choose from
Removable partial denture prosthodontics		
• Patient demands	Reduced	A priority
• Prosthesis design	"	Balanced with esthetics
• Dental materials	"	Important to select most appropriate materials
Fixed prosthodontics		
• Patient requirements	Limited	Patient needs to determine options
• Controllable factors	"	Clinical requirements dictate shade, form, surface texture, size, and position
• Dental materials	"	Select materials best suited for each case

the most appropriate dental materials for each case is equally as critical.

As will be discussed in subsequent chapters, all-ceramic crowns are not always the answer for every patient or every clinical situation. In spite of its limitations, the metal ceramic restoration has been enormously successful. What is truly remarkable is that most technicians fabricate metal ceramic restorations without the benefit of seeing the patient for whom the restoration is intended. As such, dental technicians who by virtue of their training and experience have mastered the technical skills needed to manipulate dental porcelain, are frequently identified as "ceramists" or "dental ceramists." Designations such as these are bestowed with a mixture of reverence and envy, because they set these individuals apart from their coworkers. What makes a skilled ceramist so unique is an ability to transform dental porcelain powders into vital, lifelike restorations that truly look like natural teeth.

The common thread to the above-mentioned clinical cases is the ability to re-create the position, form, texture, and color of the surrounding oral tissues.

Such work reflects the artistic skills of the dental technician and dentist, that is, the art of dental technology. Unfortunately, artistic talent alone is no guarantee of success and is best used when accompanied by a working knowledge of dental materials, that is, the science of dental technology. To blend the art and the science of metal ceramic technology you must successfully plan and fabricate metal ceramic crowns and fixed partial dentures. Toward this end, the initial chapters that follow will focus on the technical information related to the practical application of the skills introduced in later chapters.

In preparing this text, it was assumed that you, the reader, possess only entry level experience in basic laboratory procedures, or enough skill and knowledge necessary to fabricate a complete metal crown, as taught in a dental technology program or a dental school. Beyond that, nothing else was assumed. In fact, it has been presumed that the technology associated with the metal ceramic restoration fabrication is unfamiliar subject matter. As such, the topic of each chapter is introduced and explained in sufficient detail to inform rather than to confuse.



Fig 1-1 Maxillary and mandibular complete dentures with denture teeth of an appropriate size, shape, and shade along with characterization of the denture base resin.



Fig 1-2a Preoperative appearance of a patient requiring a maxillary removable partial denture.



Fig 1-2b Postoperative appearance of the patient with a characterized maxillary transitional partial denture replacing the canine and lateral incisor.

An introductory level text should be just that, *introductory*. You are encouraged to refer to more advanced reference textbooks if you desire additional technical information (Hegenbarth, 1990; Korson, 1990; Kuwata, 1980; McLean, 1979, 1980; Muia, 1982; Mütterthies, 1990; Preston, 1983, 1988; Rinn, 1990; Yamamoto, 1985).

Metal ceramic terminology

You may find that some of the descriptions and instructions in the following chapters require an expanded vocabulary of technical terms unique to the materials used or the procedures described. A working knowledge of this terminology will help you avoid confusion and any potential misunderstandings. An even more extensive "glossary of technical terms" can be found on page 173. In some instances, pertinent terms have been defined at the beginning of several chapters. Where appropriate, the revised

Glossary of Prosthodontic Terms (1987) has been used as the ultimate reference to ensure that the terminology is consistent with the accepted definitions of the specialty of prosthodontics.

Instances may arise when you detect differences in the interpretation of certain terms as compared with other publications. In such cases, an attempt will be made to identify such distinctions. The selected interpretation will be explained and used as consistently as possible throughout the text. It is for you to weigh the merits of both explanations, make a personal interpretation, and select the definition that best describes the term in question.

For example, opinions differ on how to properly describe the restorative combination of metal and porcelain. Several popular designations include: porcelain-fused-to-metal (PFM) crown, ceramo-metal crown, porcelain veneer crown (PVC), porcelain-bonded-to-metal crown (PBM), and finally, the term used in this text, the metal ceramic restoration. All these terms are acceptable in that they aptly describe the same restoration and can be used interchange-



Fig 1-3 The maxillary left central and lateral incisors are metal ceramic crowns fabricated with porcelain labial margins (Unitek's Crystar Shoulder porcelain and Jelenko's Olympia alloy).

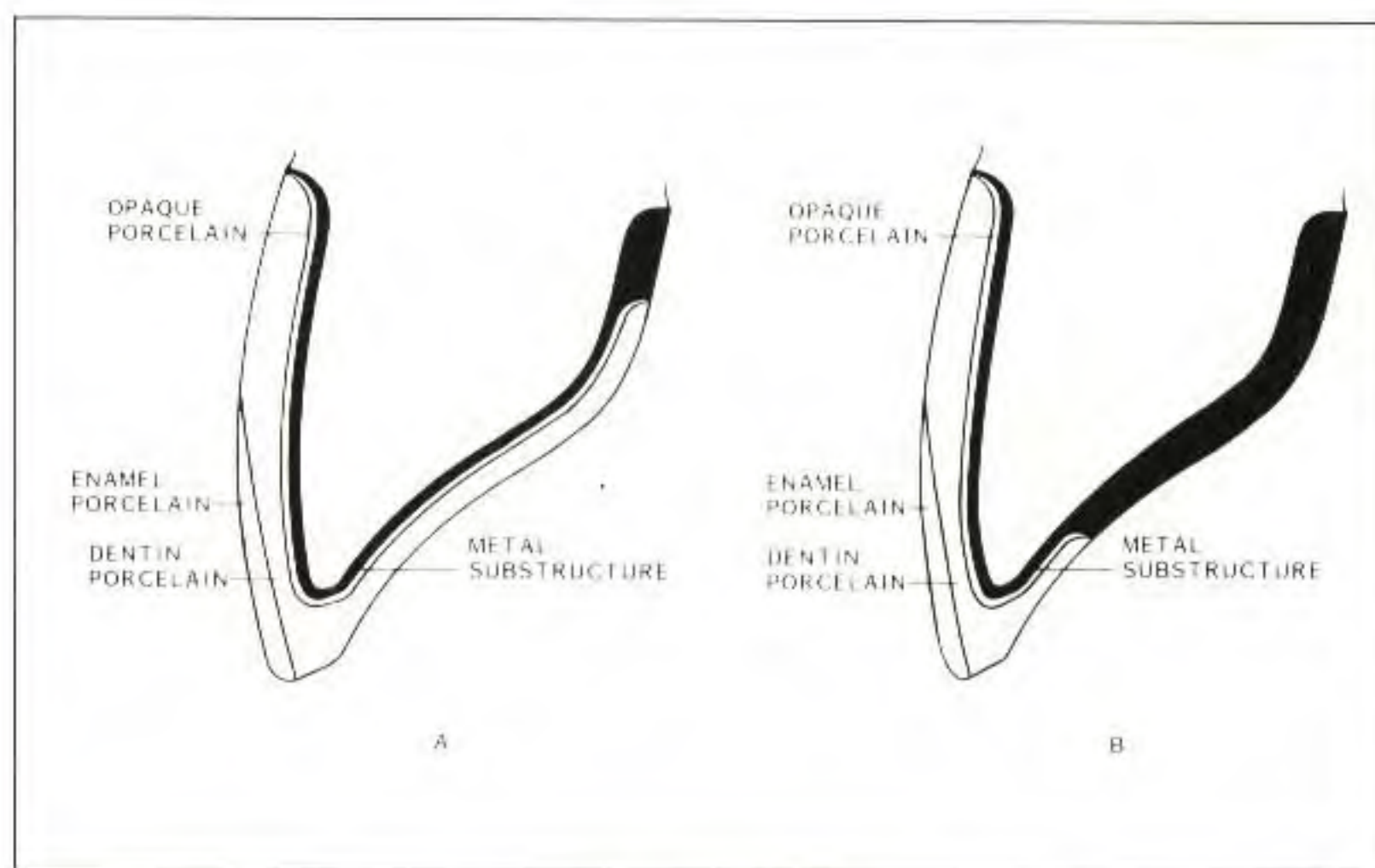


Fig 1-4 The components of a full porcelain veneer restoration include: the metal substructure (coping), the oxide layer, the opaque layer, the dentin veneer, the enamel veneer, and the external glaze (A). A partial porcelain veneer crown contains all the components of a full porcelain veneer restoration but relies on more metal to restore the occluding surfaces (lingual/occlusal) (B).

ably. However, I have chosen to be consistent with the prosthodontic community as a whole and use the designation "metal ceramic" for either a single crown or a fixed partial denture. Some general terminology includes:

1. *Metal ceramic restoration*: "a fixed restoration that employs a metal substructure on which a ceramic veneer is fused" (Glossary of Prosthodontic Terms, 1987).
2. *Porcelain-fused-to-metal (PFM) crowns*: a popular, alternative designation for the metal ceramic restoration.
3. *(Porcelain) bonding*: a term used to explain the mechanisms by which dental porcelain fuses or adheres to a metal substructure (see chapter 7).
4. *Coping*: the word coping can be used to identify the metal substructure of single-unit crowns designed for bonding to dental porcelain. Copings are made on a single tooth preparation, which may be a single unit or attached to pontics for a fixed partial denture.
5. *Framework*: this term is often applied to fixed partial dentures and identifies a one-piece substructure composed on either several copings attached to a pontic or multiple single units that are joined together as a single structure.
6. *Degassing*: the process of heat-treating a cast metal substructure in a porcelain furnace as one of the preparatory steps to applying an opaque porcelain. Subjecting the finished metal to elevated temperatures (980° to 1,050°C) in a reduced atmo-

sphere (vacuum) or in air reportedly burns off organic surface impurities and eliminates entrapped gaseous contaminants. A newer and perhaps more appropriate term—oxidizing—has emerged in the literature to describe this procedure. This latter designation will be used throughout this text.

7. *Oxidation (or oxidizing)*: the process by which a metal substructure is heated in a porcelain furnace to produce an oxide layer for porcelain bonding as well as to cleanse the porcelain-bearing surfaces of contaminants (see chapter 7).

Components of the metal ceramic restoration

In its simplest form, a metal ceramic crown or fixed partial denture has two major components: a metal substructure and a porcelain veneer. The surface oxide layer that lies between the metal and the porcelain veneer could be considered a separate component, but it is more an integral part of the casting alloy substructure. Even the dental porcelain veneer has several discrete layers, yet it functions as one mass. Consequently, the metal ceramic restoration is best considered a composite entity with a metal substructure (coping or framework), a layer of opaque porcelain, dentin and enamel veneers, and a surface glaze (Fig 1-4).

The metal substructure

Conventional low-fusing dental porcelain alone lacks the strength required of an all-porcelain restoration, so a metal substructure is added to support the porcelain veneer. The thickness of the metal coping for a single crown or a fixed partial denture can vary, depending on the type of casting alloy used and the amount of tooth structure reduced by the dentist.

The oxide layer

Most metal ceramic alloys are oxidized after the porcelain-bearing area of the restoration has been properly finished and cleaned. The metal oxides that form on the alloy's surface during this heat-treatment procedure play a key role in bonding the dental porcelain to the underlying metal substructure. Because noble elements do not oxidize, an alloy's base metal constituents are principally responsible for forming this oxide layer. Differences in alloy composition require that oxidation techniques be alloy specific.

Ideally this oxidation should be no more than a discrete, monomolecular film on the alloy's surface for all metal ceramic alloys, irrespective of compositional differences. The chemical nature of that film generally differs among the various alloy systems, as will be discussed in chapter 3. Furthermore, the role these oxides play in bonding dental porcelain to metal is explained in detail in chapter 7.

The opaque porcelain layer

Because dentin and enamel porcelains must possess some degree of translucency to mimic natural tooth structure, they lack the ability to block the dark color of the metal substructure. The opaque porcelains were formulated to serve three major functions: (1) to establish the porcelain-metal bond, (2) to mask the dark color of the metal substructure, and (3) to initiate the development of the selected shade of porcelain.

The precise dimension of a fired opaque layer varies among different brands of dental porcelain and the color of the oxidized metal substructure to which it is applied (Avila et al, 1985; Naylor, 1986; Terada et al, 1989). A uniform thickness of 0.2 to 0.3 mm generally is regarded as ideal (Barghi and Lorenzana, 1982; Terada et al, 1989). However, all brands of opaque porcelains are vacuum fired on the metal substructure in a dental porcelain furnace (see chapter 8).

The dentin porcelain veneer

While porcelain shade (color) development begins with the opaque layer, the major color contribution is derived from the pigmented metal oxides in the dentin body porcelain (see Fig 1-4). It is this initial layer of dental porcelain that imparts the dentin shade associated with, but not confined to, the gingival two thirds of a tooth. During the fabrication process the dentinal layer is overbuilt slightly, cut back, and overlaid with enamel porcelain in those sections of the restoration where greater translucency is desired. For more accurate shade duplication, estimates of the combined thickness of fired dentin and enamel porcelains range from a minimum of 0.5 to 1.0 mm (Barghi and Lorenzana, 1982; Shillingburg et al, 1987) to a maximum thickness of 1.5 to 2.0 mm (Shillingburg et al, 1987; Yamamoto, 1985).

Porcelain that is built (stacked) and fired above this 2-mm maximum height is considered unsupported by metal and more prone to fracture. Harmful stresses can form in thick, unsupported porcelain sections, thereby increasing the risk of crack propagation within the veneer. For uniformity of shade and maximum strength, it is highly desirable to have an even thickness of porcelain covering the metal substructure. By some estimates, the minimum total thickness of porcelain may be between 1.2 to 1.3 mm at the middle one third of the restoration and 1.5 to 1.6 mm at the incisal edge (Yamamoto, 1985).

The enamel porcelain veneer

This portion of the veneer has intentionally not been labelled the "incisal" layer so you would not mistakenly conclude that these porcelains must be restricted to the incisal one third of a buildup. These are enamel powders and as such it is appropriate to place them wherever natural enamel translucency is required—even if that placement is outside the incisal one third of an anterior crown or the occlusal one third of a posterior metal ceramic restoration.

In general, enamel porcelains are used largely in the incisal and interproximal areas, but they need not be limited to these areas of every porcelain buildup. To re-create the translucency and the vitality of natural tooth structure, the dentin buildup should underlie the incisal edges as well as individual cusp tips.

The enamel layer is applied and vacuum fired with the dentin buildup. It is unwise to fire the dentin and enamel layers separately, because the blending of shades is not as lifelike as when they are sintered together.

The external glaze

The natural luster of an unrestored tooth is reproduced by the development of a sheen over the external surface of the fired porcelain (see Fig 1-3). The final processing step in the fabrication of a metal ceramic restoration is to fire the completed work to a temperature (recommended by the porcelain manufacturer) to produce what is often referred to as an "auto-," "self-," or "natural" glaze.

An alternative glazing method is to apply and fire an artificial glazing porcelain to seal the exterior surface to re-create this natural sheen. The most common practice for both techniques is to air-fire the restoration and hold it at a high temperature until the desired degree of luster and maturation are attained; details of the step-by-step procedure of glazing are included in chapter 9.

In some instances, mechanical polishing on a lathe using a rag wheel with a fine diamond paste or other polishing agents (such as Brasso mixed with flour of pumice) provides a lifelike finish.

Summary

A brief history of ceramics, definition of terms, and introduction to the components of the metal ceramic restoration have been discussed. It is now appropriate to take a closer look at dental porcelains. Chapter 2 will provide you with an overview of the chemistry of metal ceramic porcelains as we know them today. The various types of porcelain powders are identified and described in terms of both composition and use.

DropBooks

The Chemistry of Dental Porcelain

Introduction

To many students of dental technology the subject of ceramic materials, and dental porcelain in particular, is one vast mystery. First came the porcelain jacket crown. Then the secrets of bonding porcelain to metal were unravelled. But dentistry in the 1980s witnessed the introduction of injection molded ceramics (Cerestore, Johnson & Johnson Co), castable ceramics (Dicor, Dentsply International Inc), strengthened low-fusing porcelains (Optec HSP, Jeneric/Pentron Industries), and aluminous porcelain (Vita Hi-Ceram, Vident). In addition, new all-ceramic systems continue to evolve (eg, Vita In-Ceram, Vident).

It is easy to find information on the various constituents of porcelain and the processing techniques used to transform ceramic materials into their final form; you can always turn to chapters on porcelain in either a dental materials text or a book devoted primarily to the subject of ceramics. Unfortunately, these discussions are also very technical and often confusing at first glance. They may even appear intended for individuals with advanced degrees in chemistry rather than the general reader. Add to this the fact that the terminology found in these various texts differs, and the subject of ceramics suddenly gets even more perplexing. For example, some authors refer to porcelains as "ceramics" (Craig, 1985), while others describe them as "feldspathic" or "dental" porcelains (McLean, 1979). You may become more confused by descriptions of the varieties of porcelains.

Consequently, an attempt has been made to present a simplified explanation of:

1. The various types of dental porcelains (their classification)
2. What raw materials make up the porcelain powders (chemical composition)
3. Which porcelains are used in the fabrication of the

metal ceramic crown (varieties of low-fusing porcelains)

4. The materials actually found in a typical metal ceramic porcelain kit.

Before delving too far into this subject, you should become acquainted with the terminology commonly used to describe dental porcelains. Several key terms are introduced in the technical descriptions that follow, but do not hesitate to refer to the Glossary of Technical Terms (page 173) for additional terminology and definitions.

Terminology

Dental porcelains actually are noncrystalline *glasses* (McLean, 1979) and whether by convention or convenience are often simply referred to as *ceramics*. Because their major component is feldspar, some prefer to describe them specifically as "feldspathic" or "dental" porcelains as opposed to the more general term ceramics (McLean, 1979).

In order to develop the color necessary to match natural teeth or the opacity required to mask a metal substructure, metallic oxides are added to the porcelain powders. As will be described later, chemical compounds, termed *glass modifiers*, are mixed with the porcelains to produce specific physical properties and handling characteristics.

To better understand feldspathic porcelains, in general you should know how dental porcelains are classified.

Classification of dental porcelains

Porcelains vary not only in their chemical composition but their use. Furthermore, not all feldspathic porce-

lains are intended for bonding to a metal substructure. What dental porcelains have in common, and yet what makes them distinct from the materials in ceramic pottery, is their reliance on feldspar. It is feldspar that forms a glass matrix to which other ingredients are added, creating several varieties of porcelains that have various applications. These variations in composition produce different properties and determine how feldspathic porcelains are classified.

Three major groups of dental porcelain are generally recognized, and each is identified according to its respective fusing (maturing) temperature range (Phillips, 1982):

High-fusing	2,350° to 2,500°F (1,288° to 1,371°C)
Medium-fusing	2,000° to 2,300°F (1,093° to 1,260°C)
Low-fusing	1,600° to 1,950°F (871° to 1,066°C)

All three types of porcelain have their own unique properties, but the high- and medium-fusing porcelains are similar in both composition and microstructure. In terms of actual use, denture teeth are made from the high-fusing materials, whereas the medium-fusing porcelains most often are used to produce prefabricated pontics (ie, trupontics). The low-fusing dental porcelains, on the other hand, are specifically formulated to fuse on metal to produce the metal ceramic restoration (Lacy, 1977); consequently, they differ more in terms of composition and physical properties than the high- and medium-fusing porcelains.

A fourth type of porcelain, termed *aluminous porcelain*, was formulated by adding additional alumina to a thermally compatible low-fusing porcelain. Aluminous porcelains have been used for over 80 years to make porcelain jacket crowns, but they were not designed to veneer cast metal substructures. From a purely physical standpoint, the coefficient of thermal expansion (CTE) for an aluminous porcelain will range from 6.5 to 8.5×10^{-6} in/in/°C, which is slightly more than one half the CTE of most metal ceramic alloys (13.5 to 15.5×10^{-6} in/in/°C) (McLean, 1979; Naylor, 1986). As will be described in greater detail in chapter 3, such a large difference in expansion coefficients makes aluminous porcelain thermally incompatible with present-day metal ceramic alloys.

In fabricating a porcelain jacket crown, a special aluminous "core" porcelain containing between 40% and 50% (by weight) of added alumina replaces the metal substructure (McLean, 1979). The corresponding dentin porcelains may contain only 5% to 10%

Table 2-1 The principal components of high-fusing porcelains (Phillips, 1982)

Ingredient	Weight percentage range
Feldspar	75% to 85%
Quartz	12% to 22%
Alumina	up to 10%
Kaolin (if present)	0% to 3%

free alumina while enamel powders are predominantly alumina-free. What differentiates these dentin and enamel porcelains from low-fusing metal ceramic porcelains is their lower CTE. It is this compatibility of coefficients of thermal expansion that permits them to veneer the castable glass-ceramic substructure (eg, Dicor, Dentsply International). The end result is a restoration without a metal substructure; that is, an all-ceramic restoration. Many of the new noncast all-ceramic systems are either strengthened feldspathic porcelains or improved aluminous porcelains.

The chemical components of dental porcelain

The principal chemical components in dental porcelains include crystalline minerals, such as feldspar, quartz, alumina (aluminum oxide), and perhaps kaolin in a glass matrix (Table 2-1) (Craig, 1985; Phillips, 1982). The exact proportions of each component vary with the particular type of porcelain (high-, medium-, and low-fusing) and the specific brand, but general compositional ranges are known (Table 2-2).

Feldspar ($K_2O-Al_2O_3-6SiO_2$ and $Na_2O-Al_2O_3-6SiO_2$)

Feldspar is the ingredient primarily responsible for forming the glass matrix (Craig, 1985; Phillips, 1982). It has been used for a number of years because it lends itself so well to the fritting and coloring processes. Naturally occurring feldspar does not exist in a pure form but is a mix of two substances: potassium aluminum silicate ($K_2O-Al_2O_3-6SiO_2$, also called orthoclase or potash feldspar) and sodium aluminum silicate ($Na_2O-Al_2O_3-6SiO_2$, also referred to as albite or sodium feldspar) (Lacy, 1977; Phillips, 1982). The ratio of potash to sodium feldspar differs in a given batch of material. This is important to porcelain manufacturers, because the two types of feldspar impart quite different handling characteristics to porcelain:

Table 2-2 Percentage composition* of several low-fusing opaque porcelains

Compound	Vita VMK 68	Will-Ceram	Duceram
SiO ₂	8.00–59.00	50.0	50.9
Al ₂ O ₃	16.30–20.00	17.0	12.6
K ₂ O	8.40–10.30	11.1	11.1
Na ₂ O	5.70–7.00	5.2	3.3
SnO ₂	4.30–5.25	18.0	18.5
TiO ₂	2.70–3.30	0.3	—
B ₂ O ₃	1.20–2.50	—	1.6
Li ₂ O	—	—	1.0
CaO	1.20–1.45	—	—
F ₂	0.00–0.50	—	0.5
Sb ₂ O ₃	—	—	0.5

*Weight percentages as reported by the manufacturers.

1. Potash feldspar is found in the majority of present-day porcelain systems because of the translucent qualities it adds to fired restorations. When melted between 2,280° to 2,730°F (1,250° to 1,500°C), potash fuses with kaolin and quartz to become a glass (Lacy, 1977). The potash form of feldspar not only *increases* the viscosity of (ie, thickens) the molten glass but also aids in the control of the porcelain's pyroplastic flow (slumping) during sintering (firing). In other words, it reduces the fluidity of the molten materials and helps to maintain the form of the porcelain buildup while it is being heated to maturity in the furnace.
2. Sodium feldspar lowers the fusion temperature of the porcelain, causing it to be more susceptible to pyroplastic flow (slumping) (Phillips, 1982). Sodium feldspar does not contribute to the optical quality of translucency and is considered a less attractive substitute for potash feldspar (Muia, 1982).

Glass modifiers such as the oxides of potassium (K), sodium (Na), and calcium (Ca) oxides also act as fluxes to increase a porcelain's coefficient of thermal expansion (McLean, 1979). The addition of these alkali enables dental porcelains to approach the higher coefficient of thermal expansion level of metal ceramic alloys. The fluxes increase the porcelain's coefficient of thermal expansion by breaking up oxygen crosslinking. There is a tradeoff, however. If too much of the oxygen crosslinking is disrupted, the glass may recrystallize (devitrify). Devitrification is more likely to occur with high-expansion dental porcelains and will weaken the restoration, produce a cloudy appearance, and make the porcelain more difficult to glaze (McLean, 1979). With modern porcelains, devitrification seldom occurs if the manufacturer's recommended firing schedule is followed.

Quartz (SiO₂)

Quartz has a high fusion temperature and serves as the framework around which the other ingredients can flow. It helps prevent the porcelain buildup from slumping on the metal substructure by stabilizing the mass at high temperatures (Muia, 1982). Quartz also acts to strengthen the porcelain.

Alumina (Al₂O₃)

This third component of porcelain is considered the hardest and perhaps strongest oxide. Its coefficient of thermal expansion is similar to that of low-fusing porcelain, thus making the two materials compatible (Lacy, 1977). Alumina, which is only slightly soluble in low-fusing porcelain, improves the overall strength and increases the viscosity of the melt (McLean, 1979). As mentioned previously, glass modifiers such as potassium, sodium, and calcium oxides must be added to raise the coefficient of thermal expansion of a low-fusing porcelain to the level of metal ceramic alloys.

Kaolin (Al₂O₃–2SiO₂·2H₂O)

This particular ingredient of porcelain is a clay, formed from igneous rock containing alumina. Historically, kaolin was added as a binder and to increase the moldability of the unfired porcelain (Muia, 1982). Such a characteristic gives mixed porcelain mass and enables it to be carved. Because kaolin is also opaque, it is added in very small quantities, if at all (Claus, 1980; Phillips, 1982). Obviously, it is not found in the enamel powders because the translucency of these porcelains would be reduced. In truth, little or



Fig 2-1 Vita Lumin shade guide combined with fired tabs of the other components in the Vita porcelain system (Vident).



Fig 2-2 The Bioform shade guides (Dentsply International) are available in two styles: (*top row*) shade tabs ordered from light to dark and (*bottom row*) shade tabs ordered by hue.



Fig 2-3 The Ivoclar shades of Will-Ceram porcelain (Williams Dental Co).

no kaolin is found in modern low-fusing porcelains.

To create the powders that go into bottled dental porcelain, these crystalline minerals are mixed with the previously mentioned glass modifiers (oxides of potassium, sodium, and calcium) and other ingredients, then sintered (fired) to very high temperatures (Phillips, 1982). A vitreous (glasslike) phase is produced and preserved by quickly quenching the molten mass in cold water. The molten glass mixture shatters on contact with the cold water, and unique noncrystalline solids, called *frits*, are formed. The term *fritting* is often used to describe the process of melting, blending, and subsequently quenching the glass components to produce these noncrystalline powders.

Once the frits are made, they can be ground to the specific particle size(s) established by individual manufacturers for their particular brand of porcelain. Metallic oxides, acting as opacifiers and pigments, are mixed with the powders before bottling to provide a multitude of optical qualities (McLean, 1979). Different designations are given to the various types of manufactured powders, based on their functional role or color contribution. A complete porcelain kit might contain bottles of opaque, dentin, and enamel porcelain powders along with numerous color concentrates, such as opaque and dentin color modifiers, external colorants (or stains), and a colorless glaze.

The manufacturing process can be altered to effect changes in the properties of the porcelain: its viscosity, melting range, chemical durability, thermal expansion, and even resistance to devitrification (recrystallization). This may explain why there are often striking variations in the handling characteristics of different brands of porcelains.

Varieties of low-fusing porcelains

The large number of US, Japanese, and European manufacturers and distributors of low-fusing dental porcelains makes for a very competitive market. The numerous commercial porcelain brands differ in terms of chemical composition, particle size distribution, handling characteristics, shrinkage, esthetics, and cost. The products marketed in the United States frequently are matched to the commercial shade guides of Vita (Vita Zahnfabrik; Fig 2-1) and Bioform (Dentsply International; Fig 2-2). Other porcelains follow the Ivoclar (Williams Dental Company) shading system, which differs markedly from both the Vita and Bioform selections (Fig 2-3). Because of the competitive nature of the dental porcelain market, many manufacturers offer their porcelain system in all or several of the more popular shade systems: Vita-Lumin series, Bioform series, Bioform Extended Range series, and the Ivoclar series.

The basic components of a traditional porcelain kit include: opaque porcelains, dentin and enamel body porcelains, modifiers, stains, and glazes. The precise formulations of these specific component porcelains will vary among different commercial brands (Tables 2-2 to 2-4).

The newest members to many porcelain families include opacous dentins and high-fusing shoulder porcelains. Opacous (or opacious) dentin powders are more highly pigmented than conventional dentin porcelain. High-fusing shoulder or porcelain margin powders are fired (sintered) at temperatures higher than regular body porcelains and were developed for the creation of a metal ceramic restoration (single crown or fixed partial denture) with a porcelain labial margin (see Fig 1-3).

Table 2-3 Percentage composition* of several low-fusing body (dentin/enamel) porcelains

Compound	Vita VMK 68	Will-Ceram	Duceram
SiO ₂	54.70–67.00	60.9	65.3
Al ₂ O ₃	17.40–22.00	14.4	14.6
K ₂ O	8.70–10.60	14.0	10.8
Na ₂ O	6.60–8.10	4.0	6.4
SnO ₂	4.30–5.25	—	—
CaO	1.70–2.10	—	1.0
TiO ₂	0.25–0.29	0.3	—
F ₂	0.00–0.50	—	0.5
Sb ₂ O ₃	—	—	0.5
Li ₂ O	—	—	0.3
BaO	—	—	0.3
MgO	—	—	0.3
ZrO	—	0.1	—

*Weight percentages as reported by the manufacturers.

Table 2-4 Percentage composition of several low-fusing porcelain stains

Compound	Vita VMK 68*	Will-Ceram†	Duceram*
SiO ₂	60.00–67.80	65–70	62.0
B ₂ O ₃	11.40–14.00	10–15	—
Na ₂ O	5.60–6.80	7–9	12.0
Al ₂ O ₃	5.00–6.70	5–7	—
CaO	4.50–5.50	—	—
K ₂ O	3.20–4.00	3–4	10.0
BaO	1.40–1.80	—	12.0
ZnO	0.50–0.70	—	—
Sn ₂ O	—	—	2.0
F ₂	—	—	2.0
P ₂ O ₅	—	—	—
B ₂ O	—	1–2	—
C ₂ O	—	0.5–1.5	—

*Weight percentages as reported by the manufacturers.

†Mole percentages as reported by the manufacturer.

Opaque porcelains

As their name alone would indicate, these porcelains are made opaque by the addition of insoluble oxides, such as tin oxide (SnO₂), titanium oxide (TiO₂), zirconium oxide (ZrO₂), cerium oxide (CeO₂), or zircon (ZrO₂–SiO₂) (see Table 2-1). Other oxides that might be included in an opaque porcelain include rubidium oxide, barium oxide, and/or zinc oxide (Phillips, 1982; McLean, 1979; Lacy, 1977; Binns, 1983). Such oxides have high refractive indices, so they scatter light. Between 8% and 15% of an opaque powder is composed of metallic oxides, and some particles may be less than 5 μm in size (McLean, 1979; Nally and Meyer, 1970).

Even small differences in particle size distribution are thought to influence the ability of opaques to mask the color of a metal substructure (Woosley et al, 1984). That masking power is further influenced by

the amount and the color of the oxidized (degassed) metal casting (Naylor, 1986); in other words, some casting alloys produce a discrete layer of light-colored surface oxides so a thin opaque layer may effectively mask the metal surface. A casting alloy of a different composition might generate a thick, dark oxide layer (Naylor, 1986) and require a thicker opaque covering. This phenomenon is explained in more detail in chapter 7. The thickness of the opaque layer needed to veneer the metal and mask the surface oxides differs among brands of porcelain and even varies for different shades within the same porcelain system (Woosley et al, 1984; Barghi and Lorenzana, 1982). Studies have suggested a minimum dimension of 0.2 mm (Barghi and Lorenzana, 1982) and a maximum thickness of up to 0.5 mm (O'Brien, 1989) due to the wide variability among opaques and requirements of different shades. In actual practice, many opaque systems block the color of the metal adequately and

initiate shade development when only 0.2 to 0.3 mm thick (Barghi and Lorenzana, 1982). However, proper technique is required during the opaque application process to obtain a uniform thickness of opaque within this recommended range.

When mixed with color modifiers or stains, opaques can be modified to correspond to a basic body shade. Other opaque additives simulate natural fluorescence. By and large, the opaque layer serves three primary functions: (1) it wets the metal surface and establishes a metal-porcelain bond; (2) it masks the color of the metal substructure; and (3) it initiates development of the selected shade. Most porcelain systems include a set of opaque porcelains with more concentrated colorants identified as opaque *modifiers*. These modifiers are identical to the standard opaques in composition except for a greater percentage of metallic oxides for more saturated color. Typically, such porcelains are mixed with standard opaque porcelains to achieve internal shade modifications.

Body porcelains

The designation "body" porcelain is the preferred term to collectively describe four principal types of porcelain powders used to re-create the "body" of a restoration: *dentin* (body or gingival), *enamel* (or incisal), *translucent*, and *modifier* (Lacy, 1977) (see Table 2-3). These body porcelains are mixed with either distilled water or a special liquid (provided with the porcelain kit) that helps to prevent the buildup from drying out rapidly. They are applied directly over the fired opaque layer and can re-create the form and color of natural dentin and enamel tooth structure. Because the dentin, enamel, translucent, and modifier powders all have the same chemical and physical properties, they may be intermixed freely if custom shading is desired. They differ in appearance in the fired state simply because of variations in the amount and type of metallic oxide pigments each contains.

Dentin porcelains

The dentin porcelains correspond in color to the dentin of natural teeth. As will be explained later in chapter 8, the bulk of the crown buildup for most metal ceramic restorations will be in the dentin material. Therefore, dentin porcelain is the major determinant of the shade for any porcelain restoration. In many porcelain kits there is a separate dentin porcelain for every shade, although several shades may share the same enamel porcelain. Of course, all shades use the same translucent powders.

The designation dentin porcelain is generally pre-

ferred for this group of materials, although occasionally they are described as body, gingival, or cervical powders. Use of the terms gingival and cervical porcelain is discouraged because several porcelain systems contain separate gingival or cervical powders that actually have a chemical composition different from dentin powders. In fact, cervical porcelains are typically less translucent, more saturated with color, and intended primarily for placement in the gingival one third or interproximal areas. Certainly it should be recognized that the dentin porcelains are routinely incorporated into areas of a restoration other than the gingival one half of a crown. In fact, natural-looking restorations need the dentin porcelains to extend to the incisal one third or occlusal surface to underlie enamel-covered incisal edges or cusp tips.

Enamel porcelains

When fired, enamel porcelains are more translucent than dentin porcelains (McLean, 1979). They also have a more restricted range of shades. A typical porcelain system may provide only four or five bottles of enamel powders to cover the entire range of shades in the kit. The enamel porcelain shades are usually in the violet to gray range and impart a combination of true translucency and the illusion of translucency, by virtue of their grayish or sometimes bluish appearance.

Occasionally, these materials are referred to as incisal porcelains. As was the case with dentin powders, enamel porcelains are not restricted to any one area of a tooth. In fact, often they are, and should be, extended into the gingival one half to the gingival one third of a porcelain buildup.

Translucent porcelains

Practically all porcelain systems provide translucent materials, but not every accompanying technique manual describes their use in a basic porcelain buildup. However, the depth and natural translucency provided by a veneer of translucent porcelain has stimulated more manufacturers to provide this type of porcelain in their recommended basic technique.

Translucent porcelains are not transparent, they do not allow the transmission of *all* light. They are applied as a veneer over nearly the entire surface of a typical porcelain buildup. As mentioned previously, this veneer imparts depth and a natural enamel-like translucency without substantially altering the body shade that is being overlaid.



Fig 2-4 To appreciate the color and intensity of a porcelain system's body modifiers, fire sample mixes on a test restoration such as this.



Fig 2-5 As seen with the metal ceramic restoration on this mandibular second premolar, proper glazing and the addition of surface stains make for a lifelike restoration.

Body modifiers

Finally, there is a group of related materials that are referred to as body modifiers. These porcelains are more color concentrated and were designed to aid in achieving internal color modifications. Modifiers can be used full strength for vivid characterization or diluted by mixing with dentin and enamel powders for more subtle shade alterations (Fig 2-4). As mentioned earlier, because all dentin, enamel, translucent, and body modifiers have the same basic chemical and physical properties, they may be intermixed freely for custom shading. It is important to remember that modifiers are color *intense*; dentin porcelains are color *predominant*; and enamel and translucent porcelains are color *reduced* (Naylor, 1986). All these powders are basically the same material, but they do differ in appearance because of the amount and type of metallic oxide pigments they contain. A partial listing of representative basic color effects and the corresponding metallic oxides that produce those colors might include some of the following examples (Naylor, 1986):

Yellow—the predominant color in most teeth is derived from either indium or praseodymium (lemon), both of which are stable pigments.

Vanadium—zirconium or tin oxide diluted with chromium are also used but are less stable.

Green—developed from chromium oxide but avoided in dental porcelain because it has the characteristic color of glass.

Pink—derived either from chromium-tin or chrome-alumina and used to eliminate the greenish hue in the glass, thereby creating a warm tone to the porcelain. Although these pigments are stable only

to a temperature of 2,462°F (1,350°C), they are useful in low-fusing porcelain.

White—created through the use of opacifiers such as cerium oxide, titanium oxide, and zirconium oxide (zirconia), with zirconium oxide being the most popular.

Black—produced by iron oxide.

Gray—derived from platinum gray or by diluting iron oxide.

Blue—obtained from cobalt salts and used for enamel shading.

Stains and glazes

Unlike the opaque and body porcelains, stain powders contain less silica or alumina and more sodium and potassium oxide, plus special colorant oxides (Lacy, 1977) (see Table 2-4). Stains also contain high concentrations of metallic oxides, which give them greater fluidity at temperatures above 1,600°F (871°C).

Stains are created by mixing the metallic oxides with lower-fusion-point glasses—not to dilute the intensity of color but to ensure their fusion below the maturing temperature of the dentin and enamel porcelains (McLean, 1979). Such stains are helpful because they allow you to develop surface characterization and color modification for custom shade matching or harmonizing.

Glazes are generally colorless low-fusing porcelains that possess considerable fluidity at high temperature. They fill small surface porosities and irregularities and when fired help to re-create the external sheen or glassy appearance of a natural tooth (Fig 2-5).

To the highly skilled ceramist, color development

begins with the opaque layer, is enhanced by the body porcelains, and is then highlighted by a natural (or self) glaze. Keep in mind, however, that surface stains and glazes cannot provide the finite optical qualities that a matured dental porcelain's natural glaze can; they are only surface characterizations and, as such, refract light differently than do internal color modifications veneered by either dentin or enamel porcelain. As an example, incisal translucency looks far more natural when achieved with enamel or translucent porcelain, as opposed to the appearance of a layer of fired blue surface stain. Despite these limitations, stains are often a salvation because they enable you to make immediate color corrections to compensate for minor shade discrepancies (see Fig 2-4).

Color-coding dental porcelain powders

A common practice in several porcelain systems is to use organic dyes to color-code the porcelain powders (Naylor, 1986). By convention, dentin powders are pink and enamel powders are blue; the colorants merely burn off during the firing procedure so the porcelain literally turns white in color before the firing cycle is begun. These organic dyes do not affect the shade of the fired restoration in any way.

Some brands of dental porcelain are not color-coded for identification, and all the shades of dentin and enamel porcelain have the same white appearance. When distilled water is added, the dentin and enamel mixes look virtually the same. With these systems, the manufacturer may include red and blue liquid colorants (color tags—eg, Pencraft Porcelain, Jeneric/Pentron Industries) for custom coloring of each individual mix (see Fig 8-36 in chapter 8). Colored organic food dyes can be purchased and added to create a wide range of color effects when special shade modifications are involved. All liquids are color intense and only a small amount is needed to create the desired effect. However, it is only the liquid medium that is colored, not the powders themselves.

Some technicians prefer to use multiple color tags to highlight modifiers and areas of custom shading and characterization during the porcelain buildup procedure. Through custom color tags, mixtures of shade A3 and A3.5 on the same glass mixing slab can be transformed into two distinct intensities of pink. Without such differentiation, the two mixes of standard color-tagged porcelain will have the same color. Consequently, identifying the two different shades (A3 vs A3.5) would have to be based on their position on the mixing slab or by labeling the mixes by their shade or modifier numbers.



Fig 2-6 A single shade Will-Ceram sample kit (Williams Dental Co) with dentin and enamel powders plus opaque and body porcelain liquids and instruction booklet.

Once the porcelain mix is color identified, you can establish the proper consistency by adding additional distilled water or a special modeling liquid. Special liquids are useful because they do not dry out as rapidly as distilled water; this is particularly helpful during the buildup of multiple single units or for fixed partial dentures. Tap water should never be used with dental porcelain because it contains impurities that could contaminate the dental porcelain and potentially discolor the fired restoration (Naylor, 1986).

Prover (sample) kits

Many dental porcelain manufacturers, as a way of introducing a new product, offer what are called prover (or sample) porcelain kits. A typical prover kit contains bottles of the basic components of the larger, more complete system: opaque porcelain, opaque liquid, plus the corresponding dentin and enamel porcelains. You do not have to limit yourself to one shade (Fig 2-6) but may purchase prover kits with two to three shades. Generally, manufacturers are happy to furnish you with any number of shades you might want to purchase in order to acquaint you with the handling characteristics and esthetics of a new ceramic system. Customarily, surface stains are not included in prover kits.

Requirements of a porcelain for bonding to metal

At least two special features make low-fusing porcelains suitable for bonding to metal: (1) they have a high coefficient of thermal expansion (13.5 to 15.5×10^{-6} in/in/°C), and (2) they fuse (melt) below the melting range of the alloy. High-fusing, medium-fusing, and aluminous porcelains are not thermally compatible with metal ceramic casting alloys. Therefore, these porcelains would not remain attached to the metal substructure. To achieve the required thermal compatibility, porcelain veneers should have a coefficient of thermal expansion slightly lower than that of their metal ceramic alloy (see chapter 7).

The temperature range over which the porcelain fuses should be well below the melting range of the alloy that serves as the substructure. Otherwise, high temperature distortion of the metal will occur, possibly altering the fit of a restoration.

Nondiscoloring (nongreening) dental porcelains

In recent years there has been a marked increase in the number of dental porcelain systems advertised as nongreening, that is to say, able to resist discoloration by silver-containing metal ceramic alloys (Table 2-5). Because many of these products are new to the US market, little information is available to substantiate claims of resistance to discoloration. Therefore, it may be advisable to conduct your own inhouse laboratory test of this claim before you fabricate actual clinical cases (Naylor, 1990). Consider buying a prover kit and verifying the resistance to "greening" before making any major purchase of a new porcelain system or a new silver-containing alloy. Also refer to

Table 2-5 Dental porcelains advertised as nondiscoloring

Porcelain brand name	Manufacturer/distributor
Duceram	Degussa Dental, Inc
Flexo-Ceram	Elephant USA, Inc
Luxor	J.M. Ney Co
Pencraft (formerly Artis-Tech)	Jeneric/Pentron, Inc
Silhouette	Leach & Dillon
Spectrum	Dentsply International
Synspar	Jeneric/Pentron, Inc
Vita VMK 68	Vident
Will-Ceram	Williams Dental Co
Willi Geller Creation	Creation North America

the discussion on palladium-silver alloys in chapter 3 for more information on porcelain discoloration.

Porcelain firing schedules

The number of dental porcelains suitable for fusing to metal ceramic alloys introduced into the US market continues to grow at an extraordinary rate, and there is no indication that this trend will abate. While the basic process of sintering opaques, body porcelains, and stains is the same for all these systems, the actual firing techniques (temperatures and times) vary markedly among brands. Consequently, firing schedules for a number of established and new metal ceramic porcelains are given in Appendix B. These schedules were prepared with the assistance of the respective porcelain manufacturers or distributors and represent the most current information on the processing of these products at the time of writing.

Converting temperatures from Fahrenheit to Celsius

When you examine the various porcelain firing schedules, you will note that all temperatures are presented in both degrees Fahrenheit and Celsius to accommodate both US and foreign products (see Appendix B). If you need to make any additional conversions, refer to the temperature conversion chart (see Appendix D) or use the following formulas:

$$\begin{aligned}\text{Fahrenheit to Celsius: } ^\circ\text{C} &= 5/9(^{\circ}\text{F} - 32) \\ \text{Celsius to Fahrenheit: } ^\circ\text{F} &= 9/5(^{\circ}\text{C}) + 32 \text{ or} \\ &= (1.8 \times ^\circ\text{C}) + 32\end{aligned}$$

Converting the rate of rise in firing schedules

The conversion formulas listed above are used only for computing a given temperature in either Fahrenheit or Celsius to its corresponding value in degrees Celsius or Fahrenheit, respectively. However, when the *rate of rise* is converted from one scale to another, the calculations are somewhat different. For example, when a restoration is fired from 1,200°F to 1,800°F in 6 minutes, the rate of rise is determined simply by dividing the temperature increase (600°F) by the time (6 minutes) to obtain the rate: 100°F per minute. Conversely, in degrees Celsius, the temperature change would be from 649°C (or 1,200°F) to 982°C (1,800°F). This represents a 333°C increase in temperature over the 6 minutes or a 55.5°C per minute

rate of rise. Therefore, a 100°F rate of rise is equivalent to a 55°C rate of rise. [By convention, most manufacturers list the conversion as 100°F (55°C) and do not round the 55.5°C to 56°C.]

The quickest way to convert the rate of rise is simply to multiply degrees Celsius by 1.8 and *not* add the 32. Remember, this applies only to calculating the rate of rise.

Summary

At this point you should know how to classify dental

porcelains and be able to describe their chemical composition. You should also know something about the components and functions of the different types of low-fusing porcelains. Be aware that the various brands of dental porcelains can differ in their handling characteristics, their ability to mask the oxide layer, and their recommended firing schedule, yet they are all derived from the same basic ingredients.

With that introduction to dental porcelain, you now need to understand more about the alloys that are used to fabricate the metal substructure. Turn to chapter 3 for an overview of metal ceramic alloys.

DropBooks

Casting Alloys for Bonding to Dental Porcelain

Introduction

Literally hundreds of dental casting alloys are available for fabricating metal ceramic crowns and fixed partial dentures. All of these alloys reportedly are able to bond to dental porcelain, yet they differ widely in terms of composition, handling characteristics, performance, and cost.

Anyone who works with metal ceramic alloys should have a general understanding of their chemical composition, physical and mechanical properties, as well as their advantages and disadvantages. Such information is helpful in appreciating the capabilities and limitations of a particular alloy and how it might differ from similar products on the market.

This chapter begins with a brief review of the chemistry of alloys; presents the American Dental Association (ADA) classification system; introduces an alternative classification system; reviews general descriptions of the numerous metal ceramic alloys; and lastly examines several related topics of general interest.

The chemistry of metal ceramic alloys

Traditional Type III and Type IV gold-based crown-and-bridge alloys cannot be used to make substructures for the metal ceramic restoration for several reasons:

1. They are not thermally compatible with low-fusing porcelains; their coefficient of thermal expansion differs too much to permit the bonding of porcelain to metal.
2. Type III and Type IV gold alloys have melting ranges that are lower than that of dental porcelains. Consequently, these alloys would begin to melt before the dental porcelain reached its proper maturation temperature.

3. Gold-based crown-and-bridge alloys are not chemically compatible with porcelain; they were not formulated to bond with dental porcelain.

To understand the chemistry of metal ceramic alloys, it is important to begin this discussion by defining some important terms.

Related terminology

Noble (or the noun, nobility)—a term applied to metals that are corrosion- and oxidation-resistant because of an inherent chemical inertness (Craig, 1989). There are at least seven noble metals used in dentistry: gold; and the six members of the platinum group—platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh), and ruthenium (Ru). Some authors include silver (Ag) among the noble metals, except when it is used in dentistry. This exception is made because of silver's tendency to oxidize in the oral cavity (Phillips, 1982). Apparently, there are variations of nobility, leaving the term somewhat difficult to define exactly.

Nonnoble—obviously, if noble metals will not oxidize, then nonnoble metals will be expected to form oxides. Nonnoble is considered an acceptable alternative designation to the terms "base metal" or "nonprecious."

Precious—this term is applied to metals that, by virtue of their scarcity, possess a relatively high intrinsic commercial value based on supply and demand. Several examples most likely to be found in dental casting alloys include gold, silver, the six members of the platinum group, beryllium, gallium, and indium, to name only a few (German, 1979). As you can see, noble metals are precious, but not all precious metals are noble.

Semiprecious—while one of the most frequently used terms, it is also one of the most inaccurate. The

implication of the word "semi-" is that one half of the alloy is precious and the other half is nonprecious. No alloys meet this specific definition, making the description valueless. Therefore, further use of this term should be discouraged (Naylor, 1986).

Nonprecious—this designation refers to those metals (or alloys) that are not scarce and do not possess a high intrinsic value. The designation nonprecious is regarded by many as less technically correct than the preferred term base metal (Naylor, 1986). Despite this fact, the label nonprecious is ingrained in our technical vocabulary and enjoys widespread use the world over.

Base metal(s)—this is the preferred designation for nonnoble (or nonprecious) metals and alloys. When encountered in the dental literature, base metal should be interpreted as a term synonymous with nonnoble or nonprecious. Examples of base metals commonly found in metal ceramic alloys include nickel, chromium, cobalt, and aluminum, to mention just a few.

What is a metal ceramic alloy?

At least six principal features distinguish a metal ceramic alloy from both crown-and-bridge and removable partial denture alloys.

1. A metal ceramic alloy must be able to produce surface oxides for chemical bonding with dental porcelains. Take the base metal alloys for example. The major elements in these alloys are nonnoble. That means they possess a natural tendency to oxidize when subjected to the elevated temperatures of a porcelain furnace. Noble alloys, on the other hand, behave in just the opposite manner, particularly the high noble type. The noble metal components do not oxidize, so trace amounts of base elements are added in order for oxidation to take place (see chapter 6 on porcelain bonding).
2. A metal ceramic alloy should be formulated so its coefficient of thermal expansion is slightly greater than that of the porcelain veneer to maintain the metal-porcelain attachment. Even though oxides form and the metal chemically bonds to the porcelain, fracture of the ceramic veneer may occur if the metal and the porcelain are not thermally compatible.
3. The alloy must have a melting range considerably higher than the fusing range of the dental porcelain fired onto it. This temperature separation is needed so the porcelain buildup can be sintered to a proper level of maturity and can subsequently be

glazed without fear of distorting or even melting the metal substructure.

4. The alloy must not undergo distortion at the firing temperatures of the porcelain. The ability to withstand exposure to high temperatures without dimensional change is often referred to as high temperature strength or sag resistance.
5. The first four requirements must be balanced with the technician's need for ease of handling. Processing should not be too technically demanding. Any alloy that is difficult to melt, cast, finish, and polish could lose favor, despite its excellent bond strength and thermal properties.
6. A casting alloy should be biocompatible. The safety of the technician, the clinician, and the patient must not be at risk as a result of the use of a casting alloy, particularly if satisfactory alternative alloys are available.

Classification of dental casting alloys

Several methods for classifying alloys exist, but no single system has become a universally accepted standard. In fact, many different descriptions of alloys can be found in both the dental literature and in the marketing information supplied by manufacturers. It is quite a challenge to keep track of all the "new" and "improved" alloys that enter the marketplace. Moreover, grouping similar materials for comparative purposes is made difficult if an alloy's composition is not fully disclosed.

The aim of each classification method may vary in itself. One system may be based on function, while others may be established for reasons of cost, use, or alloy composition. Examples of frequently encountered classification systems include the following.

Alloy classification based on function

One of the oldest and simplest methods used to categorize casting alloys was devised by the National Bureau of Standards in 1932 (Phillips, 1982). The gold-based crown-and-bridge metals of that time were organized according to function into only four categories and described as Type I, II, III, or IV alloys. Alloys in each classification, or type, were arranged based on their gold and platinum group composition as well as their associated Vickers hardness range (Phillips, 1982). Evidently, many of these early formulations suffered one major limitation: they tarnished in the oral cavity. Thus in 1948 the classification system for crown-and-bridge alloys was modified to in-

clude specific compositional guidelines within the Type I, II, III, and IV categories, once it was learned that castings with a gold content below 65% to 75% tarnished. However it was not until 1960 that a fifth category was established for metal ceramic alloys.

With the development and introduction of the silver-, palladium-, nickel-, cobalt-, and iron-base alloys, comparisons based on hardness were no longer valid. Alloys with similar hardness values but based on different metals (silver, palladium, nickel, etc) did not necessarily possess comparable strength characteristics or function similarly. The metal ceramic alloys, in particular, did not lend themselves to categorization as Type I, II, III, or IV. They varied from this traditional classification system in terms of function, composition, and hardness.

Alloy classification based on color or composition

A second method of classification is to describe alloys according to their color and principal element or elements (Phillips, 1982). The number of subcategories varies in different sources from four to eleven.

Yellow golds—yellow color, with greater than 60% gold content

White golds—white color, but with more than 50% gold content

Low (or economy) golds—usually yellow colored, with less than 60% gold (usually 42% to 55%)

High palladium—white colored, with palladium the major component; may contain small quantities of gold (2%) and a limited amount of either copper or cobalt

Silver-palladium—white colored, predominantly silver (55% to 71%) with substantial amounts of palladium (25% to 27%) to provide nobility and to help control tarnish; may or may not contain small amounts of copper or gold

Palladium-silver—white colored, with palladium the major component, plus a substantial quantity of silver (up to approximately 40%)

One obvious limitation of this classification method is the inability to differentiate between the metal ceramic alloys and the traditional Type I, II, III, and IV crown-and-bridge metals.

The ADA classification system for cast alloys

In 1984 the Council on Dental Materials, Instruments and Equipment of the American Dental Association

Table 3-1 The 1984 ADA classification for dental alloys

Classification	Requirement
High noble	Noble metal content $\geq 60\%$ (gold, platinum, palladium) and gold $\geq 40\%$
Noble	Noble metal content $\geq 25\%^*$ (gold, platinum, palladium)
Predominantly base	Noble metal content $< 25\%$ (gold, platinum, palladium)

*There is no upper limit. This is to accommodate high noble metal content alloys with less than 40% gold.

prepared a new classification system for cast alloys based on noble metal content (Association Report, 1984) (Table 3-1). The system was devised for identification in dental procedure codes, where the intrinsic value of the metals in castings provided to patients would influence the amount of reimbursement from insurance carriers. Obviously this system of classification was not intended to indicate usage or performance levels. One of the major limitations of the ADA classification system is the fact that alloys of varied composition and performance may fall within the same general category. Such a system does not lend itself to clear communication between technician and alloy manufacturer, technician to technician, or technician to dentist. Thus, from a purely technical perspective, some other method of classification is needed to organize the wide array of dental casting alloys.

An alternative classification system for metal ceramic alloys

The ADA classification system does not group, order, or otherwise arrange the multitude of alloys which have flooded the dental market. Nor does it attempt to identify subcategories in each of the three major divisions. To address the limitations of the ADA approved classification, an alternative system of classification for metal ceramic alloys, based on composition, was devised (Naylor, 1986) (Fig 3-1). Note that all alloys are first separated into one of two major types: noble (or precious to some) and base metal (or nonnoble or nonprecious). Next the alloys are arranged by system, after which each system is further subdivided into constituent groups, if present. With this method the alloys are classified based on composition and the level of content of the major constituents.

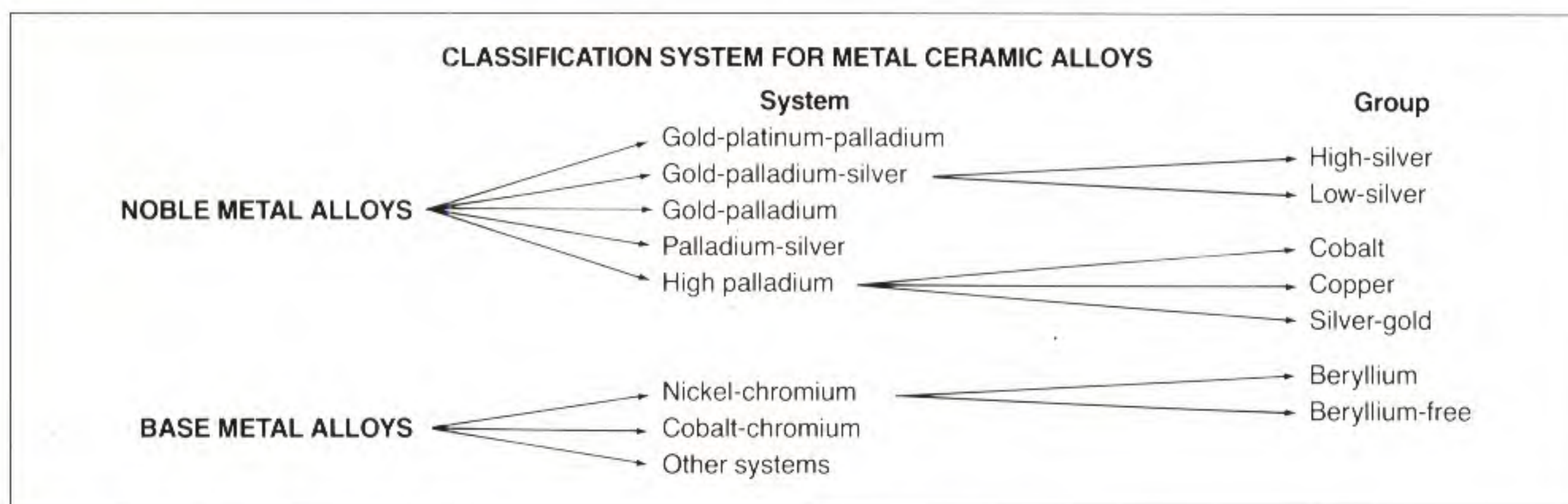


Fig 3-1 This classification system for metal ceramic alloys is based on composition.

Composition

The name of the major component in an alloy is listed first followed by the next largest constituent (Fig 3-1). Note that key trace or minor alloying elements that distinguish the performance or the properties of alloys in the same system, such as beryllium, copper, cobalt, silver and gold, are used to identify subcategories as groups.

This particular classification system is simple and easy to learn. Because it requires the identification of an alloy's composition for placement in the system, this method of classifying metal ceramic alloys also makes subsequent use of the ADA classification that much easier.

Levels of content

Gold-based alloys containing less than 70% gold are often referred to as "low" gold alloys, despite the fact that the total gold content may actually account for the majority of the alloy's composition (>50%). Obviously, the designation "low" is confusing when alloys with 10% and 69% of the same element are grouped together, although they may differ markedly in actual composition and handling characteristics. To avoid potential misinterpretations, the designations "low," "medium," and "high" are given the following values in this classification system to describe the level of the principal constituent on which an alloy is based (Naylor, 1986):

- Low 0% to 33%
- Medium 34% to 66%
- High 67% to 100%

This simple division of the total composition of an alloy into thirds permits classification in a more recog-

nizable and understandable format. Employing three equal categories encourages the use of more meaningful terminology and discourages the use of vague identifiers such as "palladium-rich" in a palladium-based alloy, or the gold level in a gold-based metal. One exception comes in describing and comparing the level of secondary or tertiary elements in alloys with a similar general composition. The gold-palladium-silver system is a good example, because it contains alloys with varying amounts of silver. Metals in this category are based on gold and have a gold content in the medium range (39% to 55%). Yet because silver is such an important constituent, it is helpful to distinguish between its two groups as high-silver and low-silver.

Description of metal ceramic alloys

A brief description of the alloy systems and groups is provided for an overview of the numerous categories in which alloys can be placed (Bertolotti, 1984; Naylor, 1986; Malhotra, 1989). The reader is advised that these descriptions contain generalizations that are probably common to many, but not all, of the members of each category. New formulations and minor variations of existing ones make it difficult to keep up with many of the changes that occur in this field. Yet most of the broader descriptions, advantages, and disadvantages (see Tables 3-2 to 3-12) are likely to hold true for new products in order for them to be placed in a given system or group.

The desired physical, mechanical, and thermal properties of an alloy are affected by more than the type of metals it contains. For example, physical properties can be influenced by many factors such as the level of purity of the ingredients and manufactur-

Table 3-2 Composition, advantages, and disadvantages of the gold-platinum-palladium alloys

Composition	
Gold: 75%–88%	Platinum: up to 8%
Palladium: up to 11%	Silver: up to 5% (if present)
Trace elements like indium, iron, and tin for porcelain bonding. (If the palladium content exceeds that of platinum, then the alloys should be classified as Au-Pd-Pt.)	
Advantages	Disadvantages
Excellent castability	High cost
Excellent porcelain bonding	Poor sag resistance so not suited for long-span fixed partial dentures
Easy to adjust and finish	Low hardness (greater wear)
High nobility level	High density (fewer castings per ounce)
Excellent corrosion and tarnish resistance	
Biocompatible	
Some are yellow in color	
Not "technique sensitive"	
Burnishable	

Table 3-3 Composition, advantages, and disadvantages of the gold-palladium-silver (high-silver group) alloys

Composition	
Gold: 39%–53%	Palladium: 25%–35%
Silver: 12%–22%	
Like the Au-Pt-Pd alloys, trace amounts of oxidizable elements are added for porcelain bonding.	
Advantages	Disadvantages
Less expensive than Au-Pt-Pd alloys	High silver content creates potential for porcelain discoloration
Improved rigidity and sag resistance	High cost
High nobility level	High coefficient of thermal expansion
	Tarnish and corrosion resistant

ing procedures, as well as the sequence in which the metals are added during the melt to create that alloy. When comparing the cost of alloys with similar compositions or with only small variations in minor alloying elements, there is no guarantee of performance although two products outwardly might appear quite similar.

As depicted in Fig 3-1, an alloy is assigned to one of two major categories: noble or base metal. In order to be considered noble, it should contain a substantial quantity of platinum group elements and/or gold. However, if these elements are absent, or if they are present in a very small quantity, the alloy's major constituents presumably are base elements and it

is classified as a base metal. Trace amounts of a platinum group element (ie, ruthenium in cobalt-chromium alloys) do not warrant classifying the entire alloy as noble. The major component clearly is the base element, cobalt. Table 3-13 contains a partial listing of representative alloys using this classification system.

Noble metal alloys

The gold-platinum-palladium (Au-Pt-Pd) system

This is one of the oldest metal ceramic alloy systems, but these alloys are not used widely today because they are very expensive. The composition range of gold-platinum-palladium alloys varies considerably, as noted in Tables 3-2 and 3-13. With some products the palladium level is greater than that of platinum, so the alloys are designated as gold-palladium-platinum metals. For other alloys palladium may have been completely eliminated, thus they are referred to simply as gold-platinum alloys (Table 3-13).

The gold-palladium-silver (Au-Pd-Ag) system

These alloys were developed in an attempt to overcome the major limitations in the gold-platinum-palladium system: poor sag resistance, low hardness, and high cost. Two variations on the basic combination of gold, palladium, and silver were created and are identified as either the high-silver (Table 3-3) or low-silver group (Table 3-4). Because these are gold-based alloys, both the high-silver and low-silver groups handle like gold-platinum-palladium metals and possess many of their general advantages and disadvantages.

The gold-palladium (Au-Pd) system

This particular system was developed to overcome the two major problems associated with the gold-platinum-silver and the palladium-silver alloys: porcelain discoloration and too high a coefficient of thermal expansion (Table 3-5). These platinum (white)-colored alloys are popular among users of noble metal ceramic alloys. However, they are not thermally compatible with some high expansion dental porcelain systems. One of the more popular formulations for this system is: gold—51.5%, palladium—38.5%, gallium—5% with trace amounts of indium and tin.

Table 3-4 Composition, advantages, and disadvantages of the gold-palladium-silver (low-silver group) alloys

Composition	
Gold: 52%–77%	Palladium: 10%–33%
Silver: 5%–12%	
Trace amounts of oxidizable elements for porcelain bonding.	
Advantages	Disadvantages
Less expensive than the Au-Pt-Pd alloys	Silver creates potential for porcelain discoloration (but less than high-silver group)
Improved sag resistance	High cost
High noble metal content	High coefficient of thermal expansion
Tarnish and corrosion resistant	

Table 3-5 Composition, advantages, and disadvantages of the gold-palladium alloys

Composition	
Gold: 44%–55%	Palladium: 35%–45%
Gallium: up to 5%	Indium and tin: 8%–12%
Indium, tin, and gallium are the oxidizable elements responsible for porcelain bonding.	
Advantages	Disadvantages
Excellent castability	Not thermally compatible with high expansion dental porcelains
Good bond strength	High cost
Corrosion and tarnish resistance	
Improved hardness	
Improved strength (sag resistance)	
Lower density	

The palladium-silver (Pd-Ag) system

This was the first “gold-free” system to be introduced in the United States (1974) that still contained a noble metal (palladium). It was offered as an economical alternative to the more expensive gold-platinum-palladium and gold-palladium-silver (ie, gold-based) metals (Table 3-6).

A classic generalization of this system is that it contains roughly 60% palladium, with the balance being silver plus additions of indium and tin. Actually, some manufacturers market two types of palladium-silver alloys. One has a palladium level near 60% (55% to 60%) with silver in the 28% to 30% range plus indium, tin, and other trace elements to make up the balance. The other variation of palladium-silver alloy will contain approximately 50% to 55% palladium, 35% to 40% silver, plus tin and other trace elements but little or no indium. Also, palladium-silver alloys

Table 3-6 Composition, advantages, and disadvantages of palladium-silver alloys

Composition*	
Palladium: 55%–60%	Silver: 28%–30%
Indium and tin	
Palladium: 50%–55%	Silver: 35%–40%
Tin (little or no Indium)	
Trace elements of other oxidizable base elements are also present.	
Advantages	Disadvantages
Low cost	Discoloration (yellow, brown, or green) may occur with some dental porcelains
Low density	Some castability problems reported (with induction casting)
Good castability (when torch casting)	Pd and Ag prone to absorb gases
Good porcelain bonding	Require regular purging of the porcelain furnace
Burnishability	May form internal oxides (yet porcelain bonding does not appear to be a problem)
Low hardness	Should not be cast in a carbon crucible
Excellent sag resistance	Noncarbon phosphate bonded investments recommended
Moderate nobility level	High coefficient of thermal expansion
Good tarnish and corrosion resistance	
Suitable for long-span fixed partial dentures	

*These compositional ranges for palladium-silver alloy better represent this alloy system than the general description of 60% palladium and 40% silver that is frequently used.

with less palladium and more silver are slightly less expensive than their counterparts with a higher palladium level. In addition, these alloys generally are cheaper than other noble, nongold-based “alternative” alloys, including the various types of high-palladium alloys.

One of the most often cited disadvantages of the palladium-silver alloys has been their tendency to “green” dental porcelain. Actually if discoloration occurs it does not always manifest itself as “greening” of the dental porcelain. In fact, such a color change is most likely to present itself as a yellow or light brown surface discoloration rather than a true “greening.” Furthermore, this phenomenon is more apt to appear at the porcelain-metal junction when it takes place (Fig 3-2). Contrary to popular belief, the mere presence of silver does not necessarily mean that the ceramic veneer will become discolored. There are at least ten commercial metal ceramic porcelains that



Fig 3-2 Three different brands of dental porcelain were all fired on copings made from the same palladium-silver alloy. However, the two nongreening porcelains (*left and right*) maintained their resistance to discoloration by silver after five body bakes whereas the conventional porcelain (*middle*) discolored substantially after two firings.

are advertised as resistant to porcelain discoloration (Naylor, 1986, 1988, 1990; Malhotra, 1989) (Table 2-5). However, little published data are available to support these claims of equal levels of resistance to discoloration (Fig 3-3).

The high-palladium system

When this system was developed, several types of high-palladium alloys were originally introduced (Tuccillo, 1987). The more popular compositions were a group containing *cobalt* (Table 3-7) and another containing *copper* (Table 3-8). Of these two formulations of high-palladium alloys, the copper group appears to be the more popular. The more commercially successful versions of these products had an advertised composition of 79% palladium and 2% gold (van der Zel and Vrijhoef, 1985; Naylor, 1986). Some manufacturers contend that a 1% to 2% addition of noble metals like gold and/or platinum improves a high-palladium alloy's grain structure (Hausselet, 1984). However, that view is not widely held, nor is it shared by this author, due to a lack of undisputed evidence.

In an effort to overcome some of the disadvantages of the original high-palladium alloys containing cobalt and copper, a second generation of high-palladium alloys evolved in which both the cobalt and copper were eliminated. Evidently the concept of a high palladium-silver-gold alloy was presented around the same period the cobalt- and copper-groups were



Fig 3-3 The metal ceramic restorations on the right and left were fabricated on a palladium-silver alloy while the crown in the middle was made with a nickel-chromium-beryllium alloy. The conventional porcelain (*left*) and a new, nongreening porcelain (*right*) both discolored on the palladium-silver alloy. The nongreening porcelain did not discolor with the nickel-chromium-beryllium alloy (*middle*), as would be expected.

Table 3-7 Composition, advantages, and disadvantages of high palladium-cobalt alloys

Composition*	
Palladium: 78%–88%	Cobalt: 4%–10%
(some high palladium-cobalt alloys may contain 2% gold)	
Trace amounts of oxidizable elements (such as gallium and indium) are added for porcelain bonding.	
Advantages	Disadvantages
Low cost	More compatible with higher expansion porcelains
Reportedly good sag resistance	Some are more prone to over-heating than high Pd-Cu
Low density means more castings per ounce (than gold-based alloys)	Produce a thick, dark oxide
Some melt and cast easily	Colored oxide layer may cause bluing of porcelain
Good polishability (supposed to be similar to Au-Pd alloys)	Prone to gas absorption
Reportedly easier to presolder than high Pd-Cu alloys	Little information on long-term clinical success

*In response to the initial popularity of the high palladium-copper alloys containing 79% palladium and 2% gold, some manufacturers have marketed a high palladium-cobalt alloy with the small addition of gold.

introduced. However, at that time little attention was focused on this particular high-palladium composition.

It was only after the high palladium-cobalt and high palladium-copper alloys failed to acquire sustained market share because of their dark oxide, poor high-

Table 3-8 Composition, advantages, and disadvantages of high palladium-copper alloys

Composition	
Palladium: 70%–80%	Copper: 9%–15%
Gold: 1%–2% (if present)	Platinum: 1% (if present)
Some, but not all, high palladium-copper alloys contain small quantities (1%–3%) of gold and/or platinum. Trace amounts of the oxidizable elements gallium, indium, and tin are added for porcelain bonding.	
Advantages	Disadvantages
Good castability	Produce dark, thick oxides
Lower cost (than gold-based alloys)	May discolor (gray) some dental porcelains
Low density means more castings per ounce	Must visually evaluate oxide color to determine if proper adherent oxide was formed
Tarnish and corrosion resistant	Should not be cast in carbon crucibles (electric casting machines)
Compatible with many dental porcelains	Prone to gaseous absorption
Some are available in 1-dwt ingots	Subject to thermal creep (marginal opening)
	May not be suitable for long-span fixed partial dentures
	Little information on long-term clinical success
	May be difficult to polish
	Presoldering may be a problem
	High hardness

temperature strength (copper group), and marginal creep (copper group), that attention turned to the high palladium-silver-gold formulation. Owing to the recent popularity of these alloys, little information is available on their performance but their general composition is known (Table 3-9). One advantage of high palladium-silver-gold alloys is their reduced cost (compared to gold-based alloys), a reported improvement in high temperature strength, and the formation of a lighter surface oxide layer (Tuccillo, 1987).

Base metal alloys

Two recognized base metal alloy systems are in use today: one is nickel based and the other is cobalt based. Alloys in both systems contain chromium as the second largest constituent. Any other types of base metal alloys represent only minor systems and need not be discussed.

Table 3-9 Composition, advantages, and disadvantages of the high palladium-silver-gold alloys

Composition	
Palladium: 75%–86%	Silver: less than 1%–7%
	Gold: 2%–6%
	Platinum: less than 1.0% (if present)
Trace amounts of oxidizable elements such as indium and gallium.	
Advantages	Disadvantages
Low cost	A relatively new alloy group
Low density	No data on long-term performance
Improved sag resistance (better high temperature strength)	Like other palladium-based alloys are prone to gaseous absorption
Light-colored oxide layer	Should not be cast in carbon crucibles

Table 3-10 Composition, advantages, and disadvantages of the nickel-chromium-beryllium alloys

Composition	
Nickel: 62%–82%	Chromium: 11%–20%
	Beryllium: up to 2.0%
Numerous minor alloying elements include, but are not limited to: aluminum, carbon, gallium, iron, manganese, molybdenum, silicon, titanium, and/or vanadium	
Advantages	Disadvantages
Low cost	Cannot use with nickel-sensitive patients
Low density permits more casting per ounce	Beryllium exposure may be potentially harmful to technicians and patients
High sag resistance	Proper melting and casting is a learned skill
Can produce thin castings	Bond failure more common in the oxide layer
Poor thermal conductor	High hardness (may wear opposing teeth)
Can be etched	Difficult to solder
	Ingots do not pool
	Difficult to cut through cemented castings

Nickel-chromium (Ni-Cr) system

These metal ceramic alloys offer such economy that they are also used for complete crowns and all-metal fixed partial dentures (Bertolotti, 1984). The major constituents are nickel and chromium, with a wide array of minor alloying elements. The system contains two major groups: those that contain *beryllium* (Table 3-10) and those that are *beryllium-free* (Table 3-11). Of the two, the nickel-chromium-beryllium al-

Table 3-11 Composition, advantages, and disadvantages of the nickel-chromium beryllium-free alloys*

Composition	
Nickel: 62%–77%	Chromium: 11%–22%
Boron (some), iron, molybdenum, niobium (or columbium), and/or tantalum.	
Advantages	Disadvantages
Do not contain beryllium	Cannot use with nickel-sensitive patients
Low cost	Cannot be etched
Low density means more castings per ounce	May not cast as well as Ni-Cr-Be alloys
	Produce more oxides than Ni-Cr-Be alloys

*Because these are nickel-based alloys, they have many of the other advantages and disadvantages of the Ni-Cr-Be group.

loys are generally regarded as possessing superior properties and have been more popular (Tuccillo and Cascone, 1983). Among other things, beryllium improves castability and lessens the tendency for these alloys to form a thick oxide at high temperatures (Association Report, 1985).

The nickel-based alloys that were introduced in the late 1960s were the forerunners of this system; however, the conclusions of the research of more than a decade ago are not always relevant to the products in today's market. Early problems with castability and fit have largely been overcome by improvements in the alloy formulations and a better understanding of the proper ways to sprue, invest, and cast these low density metals. The nickel-chromium system is in widespread use and dominates a substantial portion of the base metal market in the United States.

Cobalt-chromium (Co-Cr) system

Like the nickel-chromium system, the cobalt-based alloys have been marketed as porcelain alloys possessing the added capability to fabricate economical all-metal restorations (Table 3-12). The major constituent is cobalt, not chromium. Therefore, these metals are more appropriately described as cobalt-chromium rather than chrome-cobalt or chromium-cobalt alloys. There has been some reference to a possible subdivision of the cobalt-based system into two groups—those that contain *ruthenium* and those that are *ruthenium-free*. Whether sufficient differences exist to warrant such a division of this system is unclear. The cobalt-chromium alloys are being promoted as porcelain alloys, but they are not re-

Table 3-12 Composition, advantages, and disadvantages of the cobalt-chromium alloys

Composition	
Cobalt: 53%–68%	Chromium: 25%–34%
Trace elements include molybdenum, ruthenium (some) and/or wolfram.	
Advantages	Disadvantages
Do not contain nickel	More difficult to process than nickel-base alloys
Do not contain beryllium	High hardness (may wear the opposing dentition)
Poor thermal conductors	Oxidize more than both nickel-based alloys
Low density	No information on long-term clinical studies
Low cost	

garded with the same favor and level of success as the nickel-chromium-beryllium alloys.

Although the cobalt-chromium alloys are not as popular as the nickel-chromium-beryllium alloys, they are being advertised as "nonnickel," "nonberyllium," "nonprecious" alternatives to attract consumers of base metal who are concerned about the biocompatibility of nickel and beryllium (Association Report, 1985; Covington et al, 1985; Kalkwarf, 1984; Morris, 1987).

Other systems

This category was added to include titanium alloys and any minor systems that might exist, are not generally sold by major alloy manufacturers, yet still appear on the market. Titanium alloy research is being conducted and merits a watchful eye as efforts continue to overcome the unique demands of its technical processing and the difficulties of establishing an adherent porcelain-metal bond.

Other important features of metal ceramic alloys

Aside from a basic understanding of the composition and classification of metal ceramic alloys, there are several items of interest that warrant mention.

Alloy packaging and contents disclosure

Not all manufacturers provide sufficient product information on alloy packages to permit easy identification. Many packages list everything *but* the content. It

is important that consumers be completely aware of the composition of the materials they use and provide that information in the patient's dental record.

Ingot identification

Noble alloys typically have some ingot identification in the form of the alloy's or the manufacturer's name. On the other hand, not all base metal alloys are recognizable either by name or shape. Ingot identification is especially important for consumers who maintain several types of alloy in stock.

Alloy composition versus alloy performance

Composition is one consideration when selecting an acceptable alloy, but it should not be the sole criterion. The fact that two alloys have the same percentage composition for the major constituents is no guarantee that they will perform similarly. If an alloy has a history of proven success with your dental porcelain, there is no assurance a lesser priced product of similar makeup will demonstrate comparable performance.

Small changes to the minor alloying elements, major differences in the purity of raw materials, or differences in the alloy manufacturing process (eg, quality control, in-house refining of ingredients) are features the consumer cannot assess from an alloy package.

Casting alloy–dental porcelain compatibility

With so many alloys on the market today, it is unwise to assume that a given dental porcelain can be used with all of them. Moreover, success with the single-unit metal ceramic crown is no guarantee of suitable pairing in a fixed partial denture. Occasionally, a metal and a porcelain lack a predictable level of compatibility, and the porcelain may fracture or a portion may unexpectedly pop off the metal surface (see chapter 6 on porcelain-metal bonding). Porcelain crazes and fractures may indicate incompatibility between a metal and a particular porcelain. Unfortunately, not all casting alloy–dental porcelain mismatches are readily identifiable, so consult with your porcelain manufacturer before considering alloy substitutions.

As indicated in chapter 2, the coefficient of thermal expansion (CTE) of most metal ceramic alloys is in the 13.5 to 15.5×10^{-6} in/in/°C range. For a stable porcelain bond, the CTE of the metal should be slightly *greater* than that of the dental porcelain, if the

ceramic veneer is to be held under compression (McLean, 1979; Naylor, 1986).

The role of constituent elements

The following is an alphabetical listing of many elements that might be included in a metal ceramic alloy. It is important to remember that the role a particular element plays in an alloy can vary among alloy systems.

Aluminum (Al)

Aluminum is added to lower the melting range of nickel-based alloys. Aluminum is a hardening agent and influences oxide formation. With the cobalt-chromium alloys used for metal ceramic restorations, aluminum is one of the elements that is "etched" from the alloy's surface to create micromechanical retention for resin-bonded retainers (Maryland Bridges).

Beryllium (Be)

Like aluminum, beryllium lowers the melting range of nickel-based alloys, improves castability, improves polishability, is a hardener, and helps to control oxide formation. The etching of nickel-chromium-beryllium alloys removes a Ni-Be phase to create the microretention so important to the etched metal resin-bonded retainer. Questions have been raised as to potential health risks to both technicians and patients associated with beryllium-containing alloys (Lamster et al, 1987).

Boron (B)

Boron is a deoxidizer. For nickel-based alloys, it is a hardening agent and an element that reduces the surface tension of the molten alloy to improve castability. The nickel-chromium beryllium-free alloys that contain boron will pool on melting, as opposed to the Ni-Cr-Be alloys that do not pool. Boron also acts to reduce ductility and to increase hardness.

Chromium (Cr)

Chromium is a solid solution hardening agent that contributes to corrosion resistance by its passivating nature in nickel- and cobalt-based alloys.

Cobalt (Co)

Cobalt is an alternative to the nickel-based alloys, but the cobalt-based metals are more difficult to process.

Cobalt is included in some high-palladium alloys to increase the alloy's coefficient of thermal expansion and to act as a strengthener.

Copper (Cu)

Copper serves as a hardening and strengthening agent, can lower the melting range of an alloy, and interacts with platinum, palladium, silver, and gold to provide a heat-treating capability in gold-, silver-, and palladium-based alloys. Copper helps to form an oxide for porcelain bonding, lowers the density slightly, and can enhance passivity in the high palladium-copper alloys.

Gallium (Ga)

Gallium is added to silver-free porcelain alloys to compensate for the decreased coefficient of thermal expansion created by the removal of silver. (Concerns over silver's potential to discolor dental porcelain have greatly limited its use in systems other than palladium-silver.)

Gold (Au)

Gold provides a high level of corrosion and tarnish resistance and increases an alloy's melting range slightly. Gold improves workability, burnishability, and raises the density and the cost of an alloy. However, gold imparts a very pleasing yellow color to an alloy (if present in sufficient quantity). Unfortunately, that yellow color is readily offset by the addition of "white" metals, such as palladium and silver. Gold is a noble metal.

Indium (In)

Indium serves many functions in gold-based metal ceramic alloys. It is a less volatile oxide-scavenging agent (to protect molten alloy); lowers the alloy's melting range and density; improves fluidity; and has a strengthening effect. Indium is added to nongold-based alloy systems to form an oxide layer for porcelain bonding. Alloys with a high silver content (eg, palladium-silver) rely on indium to enhance tarnish resistance.

Iridium (Ir)

Iridium serves as a grain refiner for gold- and palladium-based alloys to improve the mechanical properties as well as the tarnish resistance. Iridium is a member of the platinum group and is a noble metal.

Iron (Fe)

Iron is added to some gold-based porcelain systems for hardening and oxide production. Iron is included in a few base metal alloys as well.

Manganese (Mn)

Manganese is an oxide scavenger and a hardening agent in nickel- and cobalt-based alloys.

Molybdenum (Mo)

Molybdenum improves corrosion resistance, influences oxide production, and is helpful in adjusting the coefficient of thermal expansion of nickel-based alloys.

Nickel (Ni)

Nickel has been selected as a base for porcelain alloys because its coefficient of thermal expansion approximates that of gold and it provides resistance to corrosion. Unfortunately, nickel is a sensitizer and a known carcinogen. Estimates of nickel sensitivity among women in the United States range from 9% to 31.9% and from 0.8% to 20.7% among men (Morris, 1987).

Palladium (Pd)

Palladium is added to increase the strength, hardness (with copper), corrosion and tarnish resistance of gold-based alloys. Palladium will also elevate an alloy's melting range and improve its sag resistance. It has a very strong whitening effect, so an alloy with 90% gold and only 10% palladium will appear platinum-colored. Palladium possesses a high affinity for hydrogen, oxygen, and carbon. It lowers the density of the gold-based alloys slightly but has little similar effect on silver-based metals. Palladium, a member of the platinum group, is a noble metal.

Platinum (Pt)

Platinum increases the strength, melting range, and hardness of gold-based alloys while improving their corrosion, tarnish, and sag resistance. It whitens an alloy and increases the density of nongold-based metals because of its high density. Platinum is a member of the platinum group and is a noble metal.

Ruthenium (Ru)

Ruthenium acts as a grain refiner for gold- and palladium-based alloys to improve their mechanical properties and tarnish resistance (like iridium). Ruthenium is a member of the platinum group and is a noble metal.

Silicon (Si)

Silicon serves primarily as an oxide scavenger to prevent the oxidation of other elements during the melt. Like manganese, silicon acts as a hardening agent.

Silver (Ag)

Silver lowers the melting range, improves fluidity, and helps to control the coefficient of thermal expansion in gold- and palladium-based alloys. Silver-containing porcelain alloys have been known to induce discoloration (yellow, brown, or green) with some porcelains. Silver possesses a high affinity for oxygen absorption, which can lead to casting porosity and/or gasing. However, small amounts of zinc or indium added to gold- and silver-based alloys help to control silver's absorption of oxygen. Silver will also corrode and tarnish in the presence of sulfur. Although silver is a precious element, it is not universally regarded as noble in the oral cavity (Phillips, 1982).

Tin (Sn)

Tin is a hardening agent that acts to lower the melting range of an alloy. It also assists in oxide production for

porcelain bonding in gold- and palladium-based alloys. Tin is one of the key trace elements for oxidation of the palladium-silver alloys.

Titanium (Ti)

Like aluminum and beryllium, titanium is added to lower the melting range and improve castability. Titanium also acts as a hardener and influences oxide formation at high temperatures.

Zinc (Zn)

Zinc helps lower the melting range of an alloy and acts as a deoxidizer or scavenger to combine with other oxides. Zinc improves the castability of an alloy and contributes to hardness when combined with palladium.

Summary

The fact that no single classification system can be used to adequately categorize and describe all metal ceramic casting alloys simply underscores the complexity of this subject. Yet with an understanding of the ADA classification and an appreciation for the classification method based on alloy composition, you should be better able to distinguish between the range of compositions of ceramic alloys. The descriptions of the different types of alloys and the roles played by their various constituents should further your understanding of alloy performance and limitations. With this background you should also be better prepared to address the issues of proper substructure design presented in chapter 4.

Table 3-13 Percentage composition of representative metal ceramic alloys*

NOBLE METAL ALLOYS

Gold-platinum-palladium

	Au	Pd	Pt	Ag	Sn	In
SMG-2 (J.M. Ney Co)	87	5	7	—	<1	<1
Ultra-Gold (J.F. Jelenko & Co)	87.5	1	10	—	+	+
Degudent H (Degussa Corp)	84.5	5	8	—	—	2.5
Rx Y-Ceramic (Jeneric/Pentron, Inc)	84	6	7	1	0.7	0.5
700SL (Leach & Dillon)	84	6	7	1.5	—	1
Will-Ceram Y2 (Williams Dental Co)	82	4.5	8	3.5	<1	<1

Gold-palladium-platinum

	Au	Pd	Pt	Ag	Sn	In
Jelenko O† (J.F. Jelenko & Co)	87.5	6	4.5	1	0.4	0.3
Image (J.M. Ney Co)	85	5	5	4	<1	—

Gold-platinum

	Au	Pd	Pt	Ag	Sn	In	Rh
Rx G (Jeneric/Pentron, Inc)	87	—	10	—	+	+	1.5
Degudent G (Degussa Corp)	86	—	10.5	—	+	<2	—

Gold-palladium-silver

	Au	Pd	Pt	Ag	Sn	In
Will-Ceram W† (Williams Dental Co)	54	26.5	—	15.5	<5	<5
Cameo† (J.F. Jelenko & Co)	52.5	27	—	16	2	2.5
Rx WCG (Jeneric/Pentron, Inc)	52	28	—	14	1	3
Special White (Degussa Corp)	45	40	—	16.5	3	4

Gold-palladium

	Au	Pd	Pt	Ag	Sn	In	Co	Cu	Ga	Zn
Olympia† (J.F. Jelenko & Co)	51.5	38.5	—	—	—	8.5	—	—	1.5	—
Eclipse (J.M. Ney Co)	52	38	—	—	—	—	—	—	—	—
500SL (Leach & Dillon)	51.5	38.5	—	—	—	8.5	—	—	1.5	—
Deva 4 (Degussa Corp)	51	38.5	—	—	—	9	—	—	<2	—
Will-Ceram W-3† (Williams Dental Co)	48.5	39.5	—	—	<1	10.6	—	—	<1	—
Deva M (Degussa Corp)	46.5	44.5	—	—	—	—	—	—	—	—
SF 45 (Jeneric/Pentron, Inc)	45	45	—	—	3.5	5	—	—	—	—

Table 3-13 continues on p 40.

Table 3-13 Percentage composition of representative metal ceramic alloys* (*continued*)NOBLE METAL ALLOYS (*continued*)

	Au	Pd	Pt	Ag	Sn	In	Co	Cu	Ga	Zn
Palladium-silver										
Jelstart† (J.F. Jelenko & Co)	—	60	—	28	6	6	—	—	—	—
Lunar (J.M. Ney Co)	—	60	—	30	+	+	—	—	+	—
Paladent B (Jeneric/Pentron, Inc)	—	60	—	28	2.5	6.5	—	—	1.5	—
Palladius-Ag (Vident)	—	60	—	27	7	5	—	—	—	1
Pors On (Degussa Corp)	—	58	—	30	6	4	—	—	—	—
Applause (J.M. Ney Co)	—	55	—	35	9	—	—	—	—	—
100SL (Leach & Dillon)	—	54	—	37	8.5	0.5	—	—	—	—
Will-Ceram W1† (Williams Dental Co)	—	53.5	—	37.5	8.5	<1	—	—	—	—
Jel-5 (J.F. Jelenko & Co)	—	53.5	—	38.5	7	—	—	—	+	—
Rx 91 (Jeneric/Pentron, Inc)	—	53.3	—	37.5	8.5	0.5	—	—	—	—
Degustar GA-2 (Degussa Corp)	2	52	—	36	7.5	<2	—	—	—	—
High Palladium										
<i>High palladium-cobalt group</i>										
	Au	Pd	Pt	Ag	Sn	In	Co	Cu	Ga	
PTM-88 (J.F. Jelenko & Co)	—	88	—	—	—	—	4	—	8	
APF (Jeneric/Pentron, Inc)	—	79	—	—	6	4	8	—	1.5	
<i>High palladium-copper group</i>										
	Au	Pd	Pt	Ag	Sn	In	Co	Cu	Ga	Ge
Option	2	79	—	—	—	—	—	10	9	—
Ultima Lite (J.M. Ney Co)	—	78.1	—	—	—	4	—	8	5	—
PG-82 (Unitek/3M)	2	80.5	—	—	—	5.5	—	5	6.9	—
Naturelle	2	79	—	—	—	—	—	10	9	—
Naturelle-Lite (Jeneric/Pentron, Inc)	—	79	—	—	—	4	—	10	7	—
200SL (Leach & Dillon)	2	79	—	—	—	—	—	10	9	—
Palladium V (Vident)	2	79	—	—	—	—	—	9.5	9	0.5
Albabond E (Degussa Corp)	2	78	—	—	<1	<2	—	11	7.5	—
Liberty (J.F. Jelenko & Co)	2	76.5	—	—	6	—	—	10	5.5	—

Table 3-13 Percentage composition of representative metal ceramic alloys* (*continued*)NOBLE METAL ALLOYS (*continued*)

	Au	Pd	Pt	Ag	Sn	In	Co	Cu	Ga	Ge
<i>High palladium-silver-gold group</i>										
Protocol (Williams Dental Co)	6	75	—	6.5	Small amounts of Sn and In					
300SL (Leach & Dillon)	6	75	—	6.6	—	6.5	—	—	6	—
Aspen (Jeneric/Pentron, Inc)	5.5	75	1	6.5	Balance = Ga and In					
Degupal G (Degussa Corp)	4.5	77.5	—	7	4	—	—	—	6	—
Legacy (J.F. Jelenko & Co)	2	86	—	<1	—	+	—	—	10	—

BASE METAL ALLOYS

Nickel-chromium

<i>Nickel-chromium-beryllium group</i>	Ni	Co	Cr	Be	Al	Mo	Ti	Ru	V	Cb	W
Rexillum III† (Jeneric/Pentron, Inc)	76	0.25	13.5	1.8	2.5	5.25	0.25	—	—	—	—
Litecast B† (Williams Dental Co)	77.5	—	12.5	1.7	—	4	—	—	—	—	—
Tech Star (Leach & Dillon)	78	—	13	1.8	—	5	—	—	—	—	—
Biobond II (Dentsply International, Inc)	80.7	—	13.5	1.8	—	—	—	—	4	—	—

Nickel-chromium beryllium-free group

	Ni	Co	Cr	Be	Al	Mo	Ti	Ru	V	Cb	W
Fortet† (Unitek/3M)	64	—	22	—	—	9	—	—	—	—	—
Neptune (Jeneric/Pentron, Inc)	62	—	22	—	—	8.5	—	—	—	3.5	—

Cobalt-chromium

	Ni	Co	Cr	Be	Al	Mo	Ti	Ru	V	Cb	W
Genesis II (J.F. Jelenko & Co)	—	53	27	—	—	—	—	3	—	—	—
Novarex (Jeneric/Pentron, Inc)	—	55	25	—	+	—	—	5	—	—	10
Ultra 100 (Unitek/3M)	—	52	28	—	—	—	—	—	—	—	—
Rexillum-NBF (Jeneric/Pentron, Inc)	—	52	25	—	+	—	—	—	—	—	14

*Exact formulations of alloys are considered proprietary information and are not always available for publication. Many of the alloys listed above also contain trace amounts of other base metals which serve as grain refiners (ruthenium), oxide scavengers (boron, silicon), and strengtheners (iron) to mention just a few.

+ elements present in unspecified amounts.

— elements not identified as being present.

†Rated "Acceptable" (by ADA Acceptance Program).

Essentials of Metal Ceramic Substructure Design

Introduction

At first glance, the process of designing and fabricating the substructure for a metal ceramic restoration may appear complex. Yet once you understand the functions and basic principles of framework design, the task can be carried out more efficiently and with greater ease.

By some estimates, a significant majority of the porcelain-to-metal bond failures occur as a direct result of improper substructure design (Stein and Kuwata, 1977). Frequently, this particular phase in the fabrication of the metal ceramic restoration is either given very little attention or is poorly understood. Errors in the preparation of the metal ceramic substructure frequently go unnoticed until the brittle porcelain veneer fails in service. Only then do these errors in design become apparent, but by that time few options are available outside of complete replacement of the defective restoration. Such replacements are not only inconvenient for the patient, they are costly to the clinician and dental laboratory. Thus, it makes good sense to spend the time necessary to understand the essentials of proper substructure design, since it will help to ensure the longevity of the final prosthesis.

Functions of the metal ceramic substructure

As stated in chapter 2, conventional, low-fusing dental porcelains when used alone would not be strong enough to sustain a porcelain restoration. So specially formulated metal ceramic alloys (discussed in chapter 3) serve as the foundation for a uniform veneer of dental porcelain. To appreciate how important substructure design is for the long-term success of a metal ceramic restoration, you need only examine the various functions served by that metal foundation. These

functions may be categorized as primary and secondary functions.

Primary functions

There are at least four primary functions of the metal substructure:

1. The casting provides the fit of the restoration to the prepared tooth.
2. The metal forms oxides that bond chemically to dental porcelain.
3. The coping serves as a rigid foundation to which the brittle porcelain can be attached for increased strength and support.
4. The substructure restores the tooth's proper emergence profile.

1. The substructure is principally responsible for the fit of the restoration. Fit should be evaluated in terms of both *seat* (incisal or occlusal gap) and *seal* (marginal opening). Although a great deal of attention is usually focused on the level of marginal integrity of a restoration, you must be equally concerned with the internal adaptation of the metal to the prepared tooth. A restoration that binds against tooth structure is apt to stress the porcelain-metal bond and most likely will not seat or seal completely. Conversely, an overexpanded metal substructure invariably will rely more heavily on the cement luting agent for its retention than on good internal adaptation, and the latter restoration is doomed to failure. A properly formed metal ceramic substructure should have what is called a *passive fit* and provide both internal adaptation (*seat*) and marginal integrity (*seal*).

2. A properly oxidized substrate can enhance the attachment between porcelain and metal. This critical bond between the two key components of the metal ceramic restoration is discussed in greater depth in chapter 7. However, suffice it to say that an improv-

erly designed or poorly contoured coping may permit stress concentrations to form as the fired porcelain cools to room temperature. In turn, these stresses in the porcelain may not manifest themselves initially, but they can appear later and possibly lead to a bond failure (Fig 4-1).

3. The metal substrate creates a rigid supporting structure that the porcelain cannot provide for itself. In order to properly perform this function, the substructure must be thick enough to resist flexure or deformation when placed in function. Simply stated, the metal should be as thick as possible for strength and rigidity yet as thin as possible so as not to compromise esthetics by adding excess bulk to the restoration. Generally, the minimum thickness of metal for the porcelain-bearing areas for a single-unit metal coping will range between 0.3 mm and 0.5 mm, depending on the type of alloy used (Fowler and Tamura, 1987; Naylor, 1986). Certain base metal alloys have sufficiently high yield strengths to permit finishing below the recommended 0.3 mm level (Weiss, 1977), but it is advisable to exercise caution when this is done.

4. The substructure should be designed to restore the proper *emergence profile* to the restoration (Stein and Kuwata, 1977). The metal component of the metal ceramic system restores tooth contour to its original form and function. Certain substructure designs involve restoration of most of the original tooth form in metal with only esthetically critical areas receiving a veneer of porcelain.

Secondary functions

The metal substructure can serve a number of secondary functions. Five of general interest include:

1. Metal occlusal and lingual articulating surfaces generally can be less destructive to the enamel of opposing natural teeth (depending on the type of casting alloy selected).
2. Fabrication of a restoration with minimal occlusal clearance has more potential for success with a metal substructure (and occlusion in metal) than the all-ceramic materials.
3. The occluding surfaces can be easily adjusted and repolished intraorally.
4. The metal axial walls can support the components of a removable partial denture.
5. The axial surfaces can house attachments (precision or semi-precision) for fixed or removable partial dentures.

The metal substructure should be designed to restore lost tooth structure. You want the porcelain veneer to have a uniform thickness that is adequately

supported by the metal substructure. There is an ideal thickness of porcelain, but it varies with the different areas of the restoration. For example, in the gingival one third, 1 mm is considered ideal. On the other hand, to enhance translucency and proper tooth contour, the ideal dimension of porcelain at the incisal or occlusal one third may range from 1.5 to 2 mm. Certainly the amount of porcelain unsupported by the metal substructure should not exceed 2 mm, because that would invite failure (Figs 4-2a and b). To achieve this uniformity in porcelain thickness, the substructure must replace, in part, the tooth form lost during preparation or as a result of dental caries or trauma.

Principles of substructure design

With an understanding of the basic functions of the substructure in mind, you may begin to appreciate and apply the logic behind designing the metal framework for individual cases. There are some basic designs from which to choose when restoring teeth in various clinical situations, but each case merits its own unique design variations. Selecting the most appropriate minor modifications for those requirements comes with time and experience. One method that has proven helpful is to follow a series of prescribed questions specifically geared to provide direction to the designing process. The questions focus on the major design considerations that must be addressed with every case, although the accompanying answers will, of course, vary from patient to patient. To illustrate how easy it can be to use a question-and-answer format for substructure design, let's examine each of five questions individually. This will illustrate how you should respond to the principles posed by the specific questions.

1. Are the occlusal contacts to be in metal or porcelain?

This information should appear on the laboratory work authorization (prescription) that is submitted with the case by the dentist. If it is not readily apparent how the occlusion should be designed, contact the clinician for clarification. When deciding whether to restore the occluding surfaces in metal or porcelain, the following concepts should be considered:

Occlusion in metal requires less tooth reduction (1 to 1.5 mm). On the other hand, and in all fairness to the technician, approximately 2 mm of occlusal re-

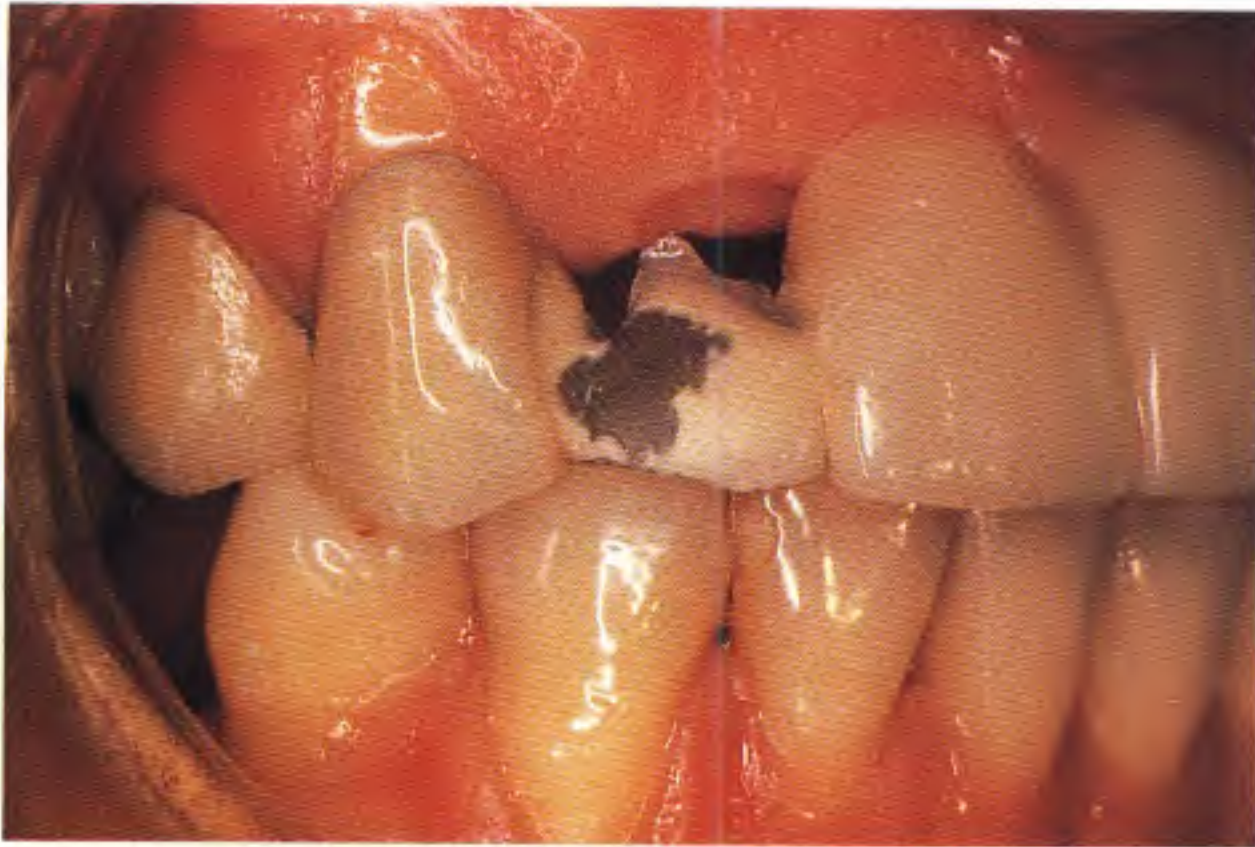


Fig 4-1 The clinical failure seen here was a direct result of a poorly designed metal substructure. (Courtesy of J.C. Kessler, DDS.)



Fig 4-2a The restoration was sectioned to reveal unsupported porcelain (over 2 mm thick in the incisal one third). (Courtesy of J.C. Kessler, DDS.)



Fig 4-2b The bond failure in the gingival one half of this pontic resulted from the release of stresses in the porcelain. The bulk of the fractured porcelain measured over 4 mm. (Courtesy of J.C. Kessler, DDS.)

duction is necessary for posterior teeth and 1 to 1.5 mm for anterior teeth requiring porcelain on occluding surfaces.

Metal surfaces can be more easily adjusted and repolished at chairside without adversely affecting the restoration. On the other hand, removing the glaze of a metal ceramic restoration during intraoral adjustments weakens the porcelain greatly (transverse strength is reduced by one half, compared to porcelain with an intact glazed surface; Phillips, 1982). Therefore, the design of restorations with occlusion in porcelain certainly would favor those dentists with the facilities and equipment to glaze porcelain as an in-office procedure. Clinicians without this capability should consider returning cases to the dental laboratory for reglazing and repolishing if extensive adjustments are required. In all probability, the number of restorations with porcelain occlusal surfaces that are adjusted and properly reglazed before delivery may be small. Therefore, it is strongly recommended that clinicians who routinely

provide metal ceramic restorations at least invest in a glazing furnace.

In general, metal is potentially less abrasive to opposing natural teeth than dental porcelain (Fig 4-3). Certainly the different types of casting alloys vary in terms of hardness and their potential to wear either enamel or other restorative materials such as cast gold crowns, amalgam, or composite resin restorations (Table 4-1). Nonetheless, the feldspathic porcelain materials are harder and potentially more abrasive than the metal ceramic alloys they are bonded to. These physical differences between porcelain and metal translate into a greater potential for porcelain to abrade any material it may oppose. This situation is particularly critical when a porcelain occlusal surface has been adjusted to the point where the glaze has been broken or the opaque layer is exposed. Invariably, an overadjustment of the porcelain can be traced to inadequate tooth preparation, or in other words, a failure to provide that 2 mm of clearance

Table 4-1 Comparative hardness values for dental ceramic, casting alloys, and human enamel

Material	Knoop hardness no. (mean KHN)	Vickers hardness no. (mean VHN)
Human enamel		
(Craig, 1989)	343	—
(Phillips, 1982)	300	—
Composite resin		
(Phillips, 1982)	55	—
Dental amalgam		
(Phillips, 1982)	90	—
Glazed feldspathic porcelain		
VMK 68 (Vita)	434	—
(Craig, 1989)	460	—
Castable glass-ceramic*		
cerammed surface	505	—
shaded surface	447	—
polished parent material	369	—
Gold-palladium alloy		
Olympia (Jelenko)	—	235
Palladium-silver alloy		
Will-Ceram W1 (Williams)	—	242
High palladium alloy		
Naturelle (Jeneric/Pentron)	—	350
Nickel-chromium-beryllium alloy		
Rexillum III (Jeneric/Pentron)	—	255

* (Naylor et al, 1990b).

needed for the recommended thickness of metal and porcelain. An exposed opaque porcelain surface is rough and cannot be polished or glazed and poses a greater danger for destruction of the opposing tooth or restoration during function.

2. Are the centric occlusal contacts 1.5 to 2 mm from the porcelain-metal junction?

If occlusal contacts are placed directly on or close to the porcelain-metal junction, there is an increased likelihood the porcelain will chip or fracture at that point of contact (Fig 4-4). Porcelain is strongest under compression and weakest under tension, so situations that induce tensile stresses in the ceramic during function are more apt to promote bond failures. For example, occlusal contacts that occur on or travel across the porcelain-metal junction during function may generate a high level of these tensile stresses or cause an area of thin porcelain to fracture. On the other hand, if the occlusal contact is on an area of metal that has been thinned excessively, the metal could flex under function and lead to bond failure.

Establish the occlusal contact either in metal or in

porcelain. A substructure should be designed so the functional incisal or occlusal contacts are located at least 1.5 mm (Rosenstiel et al, 1988) and perhaps as much as 2 mm (Dykema et al, 1986) from the metal-porcelain junction. Be particularly careful to avoid excursive jaw movements across the porcelain-metal junction whenever possible.

3. Are the interproximal contacts to be restored in metal or porcelain?

The interproximal contact areas of anterior teeth, and at least the mesial contacts of posterior teeth, are frequently restored in porcelain. Obviously a substructure design with porcelain interproximal contact areas would be more esthetic, particularly with anterior teeth. It is also important to provide proper metal support to a porcelain marginal ridge in the substructure design to prevent possible fracture (Fig 4-5). However, the distal interproximal contacts of posterior teeth may be restored in either metal or porcelain because these areas are not as critical esthetically. Technically, it is easier to add a porcelain contact area than it is to restore lost contours in metal through postsoldering. The postsoldering procedure itself is not technically difficult, but the process is time-consuming and subjects the porcelain to a potential risk of damage or contamination.

4. Are the cusp tips (or incisal edges) adequately supported by the metal substructure with no more than 2 mm of unsupported porcelain?

As has been mentioned previously, the ultimate goal of any substructure is to support an even thickness (1 mm minimum, 2 mm maximum) of the porcelain veneer. If this maximum thickness is exceeded, the ceramic layer may no longer be properly supported, resulting in a catastrophic failure at the cusp tip or incisal edge (see Figs 4-2a and b).

Remember, dental porcelain is stronger under compression than it is under tension or shear. A common design failure is depicted in Fig 4-6, A where the maxillary buccal, or shear, cusp is stressed as might occur with a bolus of hard food during mastication. The figure illustrates how the metal substructure fails to support the porcelain when it is exposed to occlusal forces. The porcelain that forms the buccal cusps is subjected to a shearing force that could possibly fracture the unsupported porcelain. In contrast, the ceramic veneer in Fig 4-6, B is supported when subjected to that same occlusal load. With a correctly designed substructure, the porcelain is un-



Fig 4-3 Dental porcelain, with its high Knoop hardness, can be destructive to opposing natural teeth and other restorative materials. Note the severe wear of these mandibular central incisors (arrow), which oppose maxillary central incisors restored with metal ceramic crowns.



Fig 4-4 This chipped incisal edge of porcelain on the maxillary right lateral incisor was caused by improper substructure design. The patient was occluding on the porcelain-metal junction during lateral mandibular movements.



Fig 4-5 The metal framework of this fixed partial denture did not provide adequate support, and the mesial marginal ridge fractured.

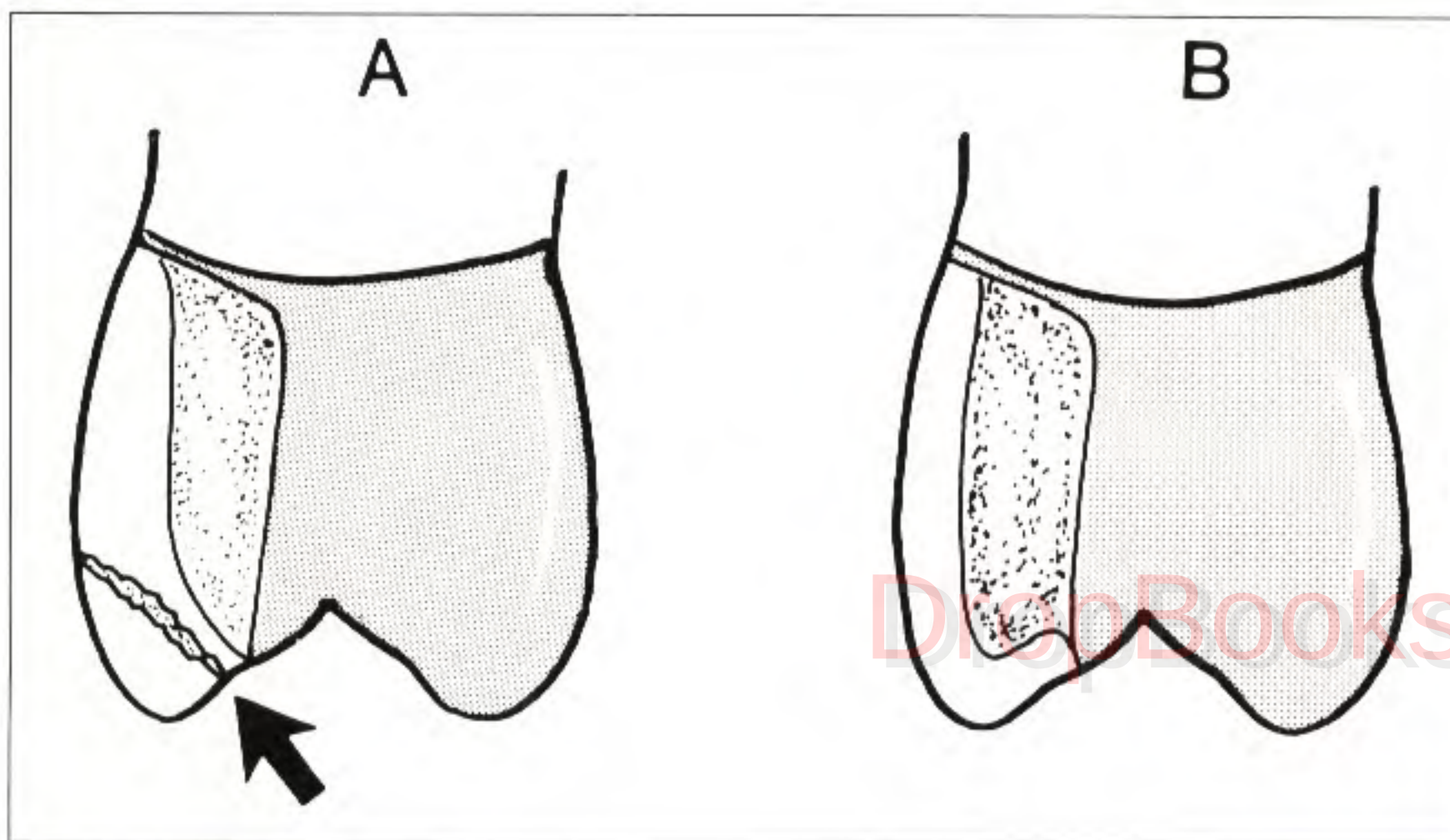


Fig 4-6 (A) The application of a force (arrow) to the buccal cusp of a crown with this substructure design can result in a shear fracture. (B) With proper buccal cusp support, the same forces put the porcelain more under compression than shear.

der compression, enabling the restoration to better withstand the forces of occlusion.

This same design principle applies to the preparation of substrates for both maxillary and mandibular posterior restorations.

5. Is the substructure thick enough to provide a rigid foundation for the porcelain veneer?

Areas to be veneered with porcelain must be at least 0.3 mm thick. Some authors argue that with base metal alloys, the coping can be reduced to 0.2 mm or less and still be strong enough to support the porcelain (Weiss, 1977). However, when you take into account the attention to detail required to finish metal to a 0.1-mm thickness and consider that many of these alloys produce dark oxides that require an

increased thickness of opaque porcelain to adequately mask the oxide layer, the potential advantage may be insignificant (Yamamoto, 1985).

Bear in mind that there is no maximum thickness of metal. For example, in instances where a major portion of a tooth has been lost to caries, fracture, or a previous restoration, the metal substructure may be 2 mm or even 3 mm thick. Such a dimension is required to reestablish the lost tooth form and ensure a uniform thickness of porcelain in the completed restoration.

Additional demands are placed on the connector areas of fixed partial dentures. The simplest rule for connector design is to create as large a surface area as possible without impinging on gingival tissues or interfering with esthetics (Riley, 1977). But a connector that is of insufficient bulk in either a labiolingual or incisogingival dimension is apt to flex under function (Riley, 1977).

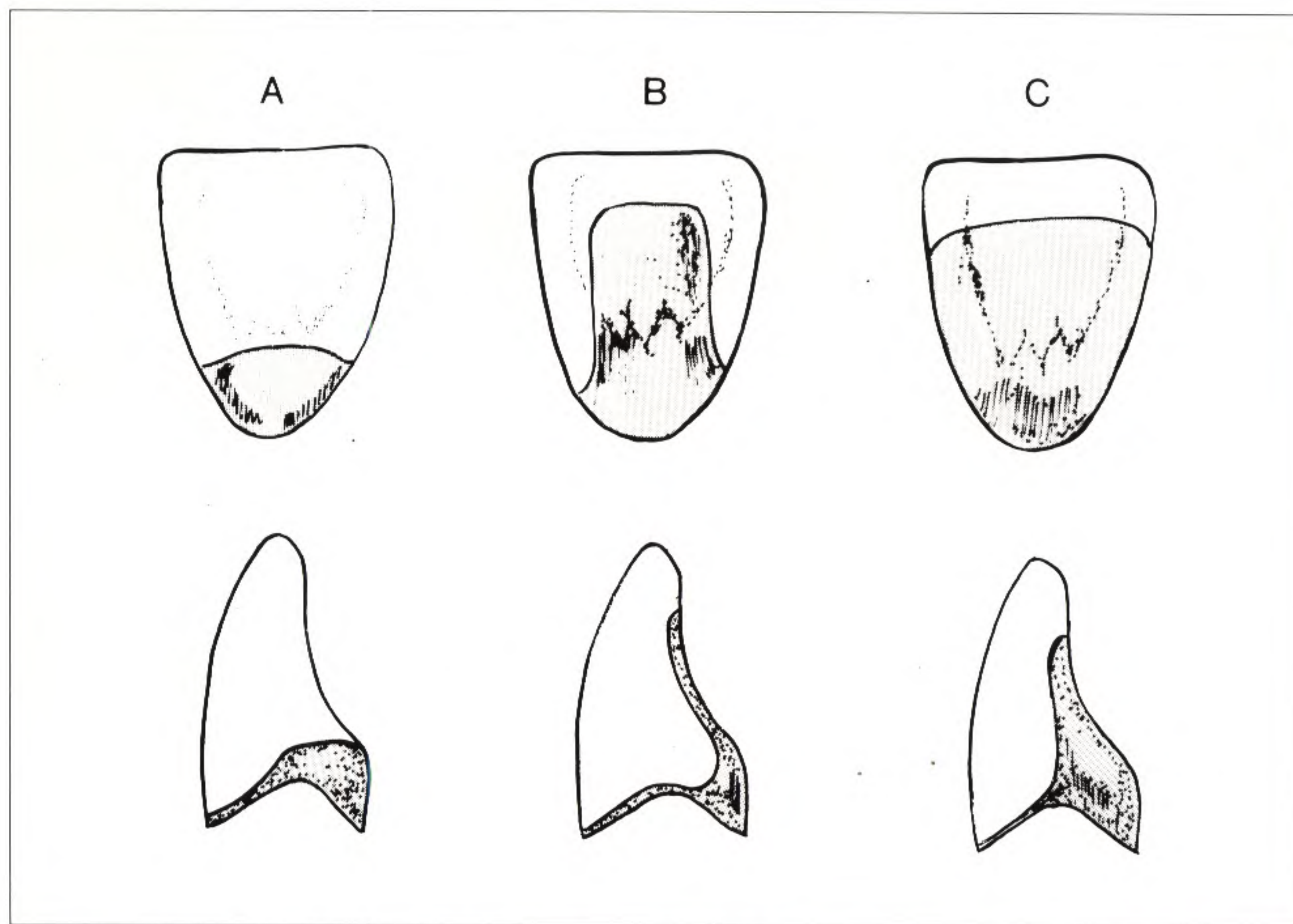


Fig 4-7 There are several design options for maxillary anterior teeth. (A) When esthetics are paramount and adequate tooth structure is present, the lingual surface may be veneered in porcelain. (B) The metal lingual surface may also be modified so the marginal ridges are in porcelain for maximum light transmission, yet the principal functional area is restored in metal. (C) The lingual surface may be restored in metal. Of course, variations of these basic three designs are also possible.

The design principles for metal ceramic pontics and connectors will be discussed later in this chapter. An understanding of these basic principles is imperative when designing substructures for the variety of clinical situations encountered.

Single-unit restorations

Procedures for maxillary anterior substructure designs

When restoring maxillary anterior teeth, more emphasis is placed on esthetics than any other single requirement. This can create a conflict that all technicians and clinicians can expect to encounter from time to time. Realistically, not every case lends itself to ideal substructure design. Therefore, do you rigidly

follow design principles at the expense of esthetics, or do you attempt to achieve maximum esthetics at the expense of an ideal design and risk mechanical failure of the restoration?

Three basic design options for maxillary incisors are illustrated in Fig 4-7. The major difference in these configurations is in the shape and height of the lingual surface. Of course, combinations of these designs are often used. However, the extent to which the lingual surface is restored by porcelain or metal is dictated by two factors: location of occlusal contacts (if present) and amount of clearance (tooth reduction) with the opposing dentition.

Location of occlusal contacts

If the mandibular anterior teeth contact the lingual surfaces of the maxillary anterior teeth in centric occlusion, the location of those contact areas should be identified with articulating film. When these occlusal contacts appear in the incisal one half of the

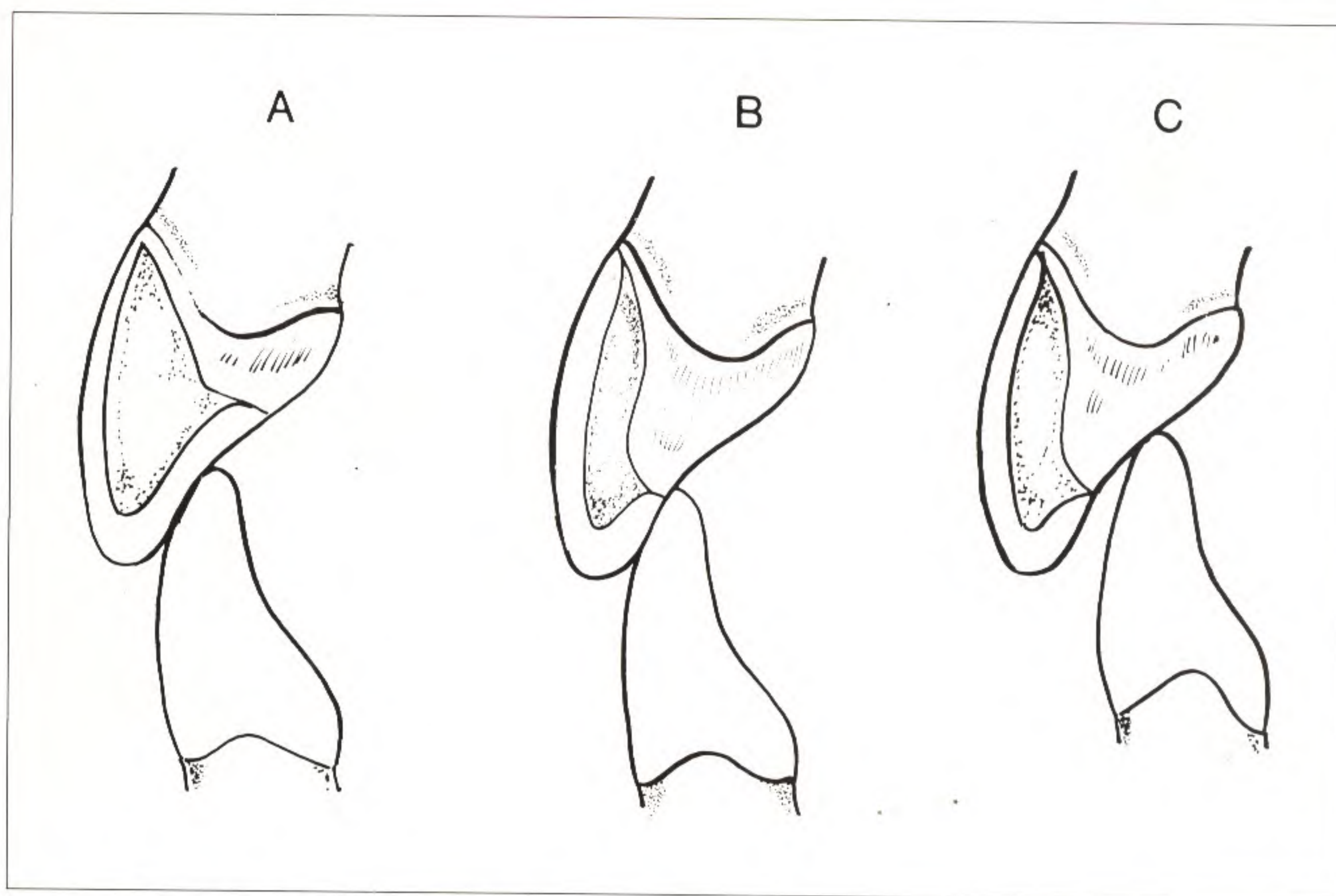


Fig 4-8 (A) When the anterior teeth contact in the incisal region, it is often necessary to consider a design with the lingual surface in porcelain to avoid functioning on or over the porcelain-metal junction. (B) Do not design the substructure so contact occurs at the porcelain-metal junction. (C) When the anterior teeth occlude in the gingival one half of the maxillary teeth, or when the lingual tooth reduction is less than 1 mm, it is best to design the substructure with the occlusion in metal.

restoration (Fig 4-8, A and B), then the porcelain veneer may be extended over the incisal edge for occlusion in porcelain. If, on the other hand, these centric occlusal contacts appear in the gingival one half of the lingual surfaces of maxillary anterior teeth (Fig 4-8, C), they should be restored in metal rather than porcelain.

According to the concept of mutually protected occlusion (also known as canine-protected occlusion or organic occlusion), in centric occlusion the anterior teeth are out of contact by approximately 25 μm or two thicknesses of shimstock (Artus Occlusal Registration Strips, Artus Corp) (Shillingburg et al, 1981). The design of the lingual aspect of the metal ceramic substructure should then be based on the clinician's preference of restorative materials (metal versus porcelain) and the amount of clearance.

Amount of clearance (tooth reduction)

One of the advantages of restoring the lingual sur-

faces of anterior teeth in metal is that the maximum amount of needed tooth reduction ranges from 0.7 mm to 1 mm. To restore these contact areas in dental porcelain would require at least a 1-mm clearance to accommodate the recommended thicknesses for the metal substrate and the ceramic veneer. It is technically possible to restore the lingual surface in metal with less than 0.7 mm of lingual tooth reduction, but such a situation is not ideal for all types of metal ceramic alloys and it does limit your ability to restore natural lingual anatomy to the final restoration.

Regardless of the location of the occlusal contacts or the amount of tooth reduction, contacts at or near the porcelain-metal junction should be avoided (see Fig 4-4). If possible, the incisal porcelain should overlap the incisal edges of the coping onto the lingual surface to reproduce the appearance of natural incisal translucency. This overlap can be as little as 2 mm; however, a substructure that does not include this design feature may account for failures in anterior restorations.

Wax pattern fabrication for anterior copings

Wax pattern fabrication need not be made more difficult than it really is. By following a few simple procedures, satisfactory wax patterns can be produced as a matter of routine.



Fig 4-9 The tooth to be restored is then waxed to its full and correct anatomical contour. This is probably the most frequently ignored step in the entire waxing procedure. Do not rely on "eyeballing" the contours of the wax pattern as the means to achieving the proper design. Individuals who appreciate the importance of proper contour are more likely to rely on the full-contour waxup technique than on "free-hand" waxing. In fact, many highly skilled technicians insist on waxing to full contour even for "simple" single-unit restorations. As with so many procedures in dentistry, those individuals most in need of an established procedure, such as waxing to full contour, are the ones least likely to recognize their limitations and the benefits of this technique.



Fig 4-11 Scribe a line across the labial surface between 0.5 and 1 mm above the marginal finish line. Also, scribe a line across the labial surface 1.5 mm from the incisal edge.

Maxillary anterior substructures with a metal lingual surface (Figs 4-9 to 4-26)

The first step in any waxing procedure is to obtain a wax coping that is well adapted to the die. Discard any patterns that contain voids between the wax and



Fig 4-10 After completing the full-contour waxup, determine the location of the patient's centric and excursive occlusal contacts, then scribe a line for the position of the porcelain-metal junction at least 1.5 mm and as much as 2 mm from the closest occlusal contact. Mark the wax pattern just lingual to the interproximal contact areas to indicate the most *labial* position of the metal interproximally, assuming the contact areas are to be restored in porcelain.



Fig 4-12 Remove the die and wax pattern from the master cast. Connect the lines drawn for the porcelain-metal junction on the lingual surface with the interproximal lines. You should end up with a continuous outline for the areas of the wax pattern that are to be cut back.

die, because such discrepancies will unnecessarily increase the contour of the restoration. A discrepancy of only 0.2 to 0.3 mm can have a very significant adverse effect on the esthetic results of a metal ceramic restoration. The master die can be dipped, or

wax can be applied directly to it in large increments with a hot spatula. With either technique you must visually inspect the internal aspect of the coping to confirm that the wax is well adapted before you proceed to the next step.



Fig 4-13 Reduce the incisal edge by at least 1.5 mm to provide sufficient space to re-create the appearance of natural translucency yet avoid excessive unsupported porcelain (>2 mm).



Fig 4-14 The wax pattern is now ready to be cut back. The objective of the cutback procedure is to remove a uniform thickness of approximately 1 mm of wax from all proximal surfaces of the substructure to receive porcelain. To aid in the cutback, first make a 1-mm depth cut in the midfacial surface of the wax pattern. Follow with similar depth cuts at both the mesial and the distal line angles.



Fig 4-15 Remove all the wax between two of the depth cuts and stay within the outline of the porcelain-metal junction.

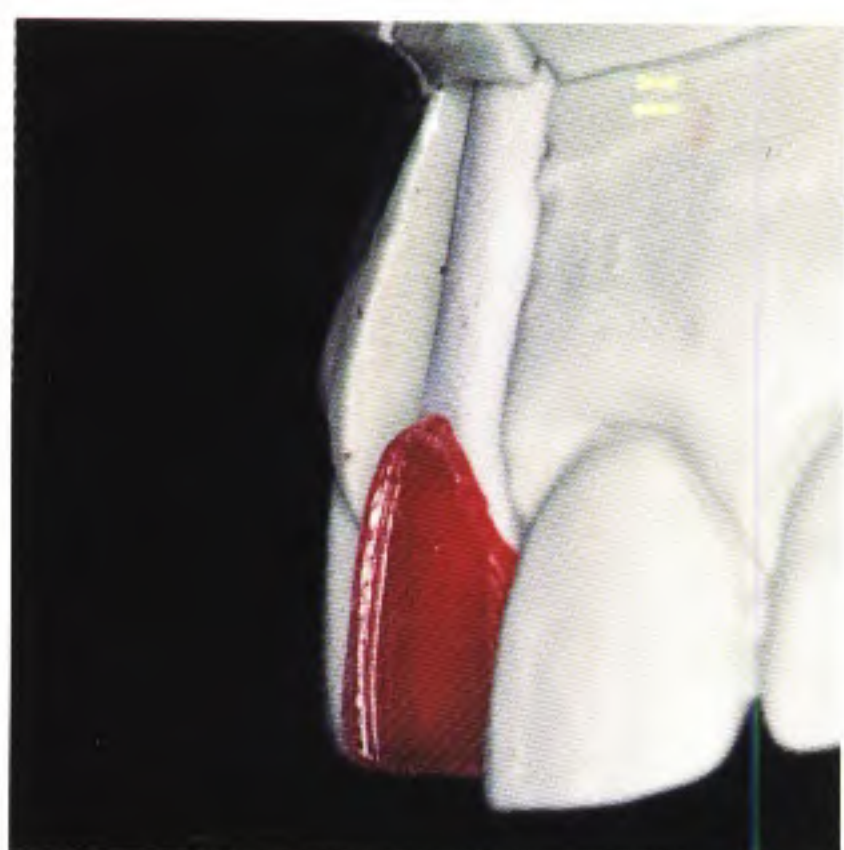


Fig 4-16 With one half of the facial surface still intact, examine the profile of the cutback to ensure that a uniform thickness of wax is removed.



Fig 4-17 Use a discoid carver, or similar instrument, to refine the porcelain-metal junction on the labial and lingual surfaces. The shape of the instrument will create a cutback with a sharp external finish line and a rounded internal line angle.

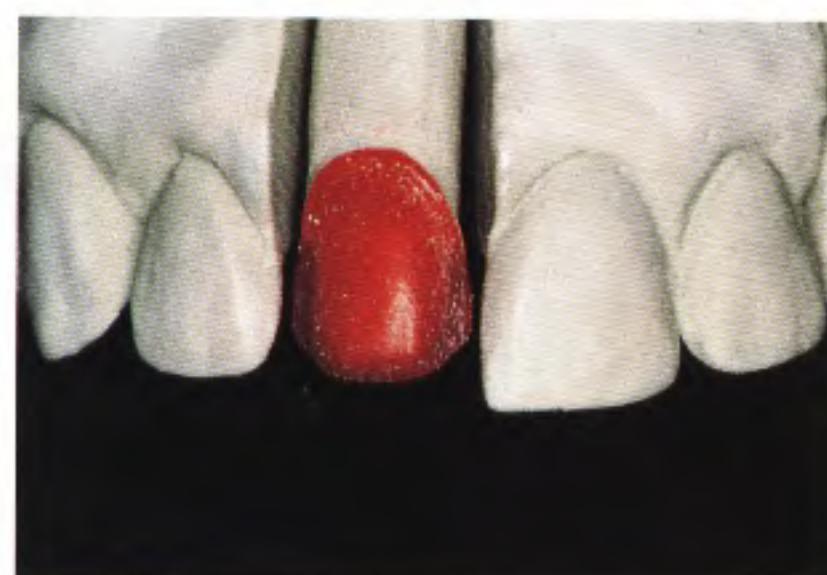


Fig 4-18 Evaluate the cutback on the master cast for proper extension and adequate clearance by viewing it from all angles—labial, lingual, and incisal.

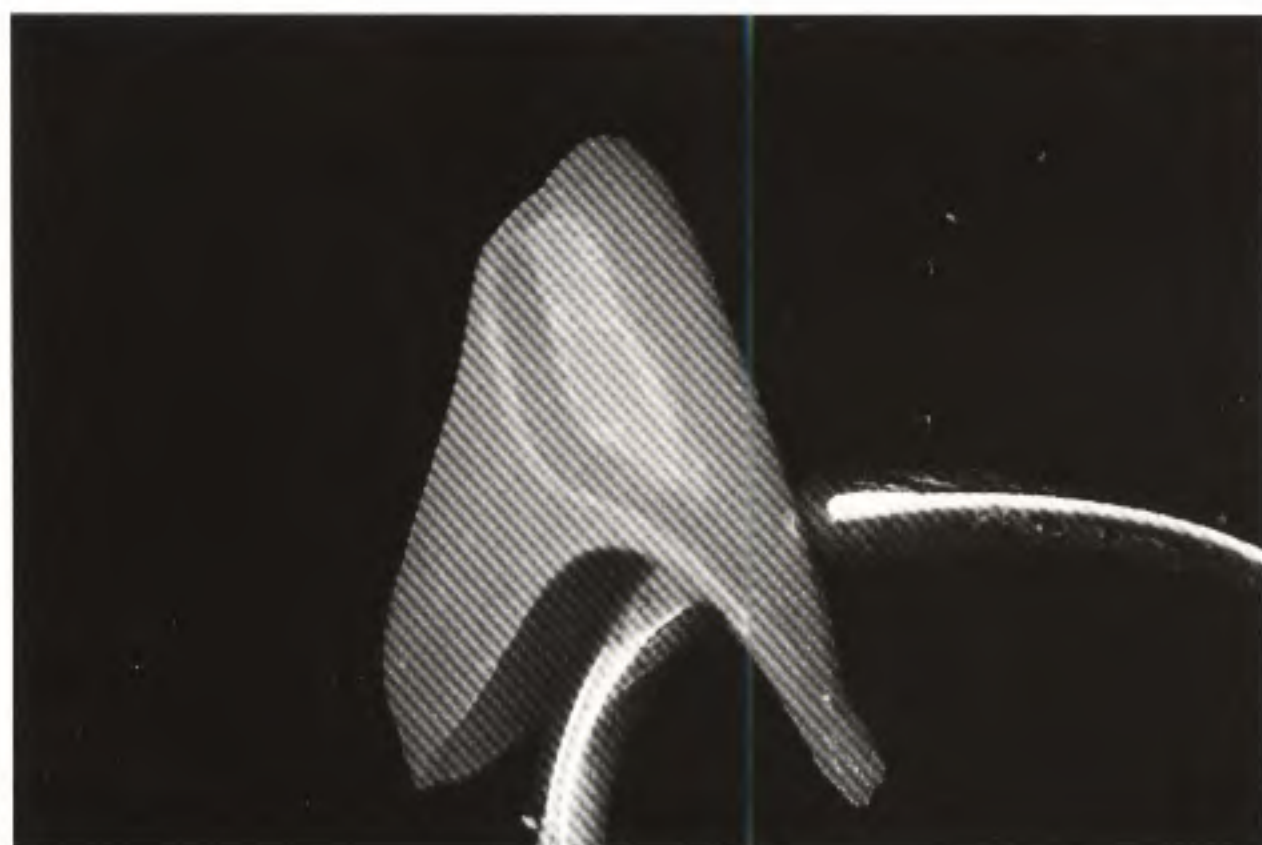


Fig 4-19 Measure the thickness of the wax pattern with the rounded tips of the Iwanson wax calipers. The thickness of the porcelain-bearing area of the wax pattern should be between 0.3 and 0.5 mm, depending on the type of alloy used and the requirements of the particular case.



Fig 4-20 Smooth any sharp line angles to produce rounded contours. A cotton swab or Q-tip moistened with debubbler and warmed by a flame can be used for this procedure. If the substructure is to have a labial metal collar, seal the margins before cutting back in this area. Leave at least a 0.3- to 0.5-mm height to the labial collar and allow metal finishing to reduce it to its final dimension. The height of the labial metal collar will be determined by the length of the labial bevel, assuming a bevel is present on the preparation. However, when the tooth has been prepared with a very wide bevel, esthetic consideration may demand that the collar's final dimension be reduced to only 0.3 mm. (There are several acceptable finish line designs, which will be discussed later in this chapter).

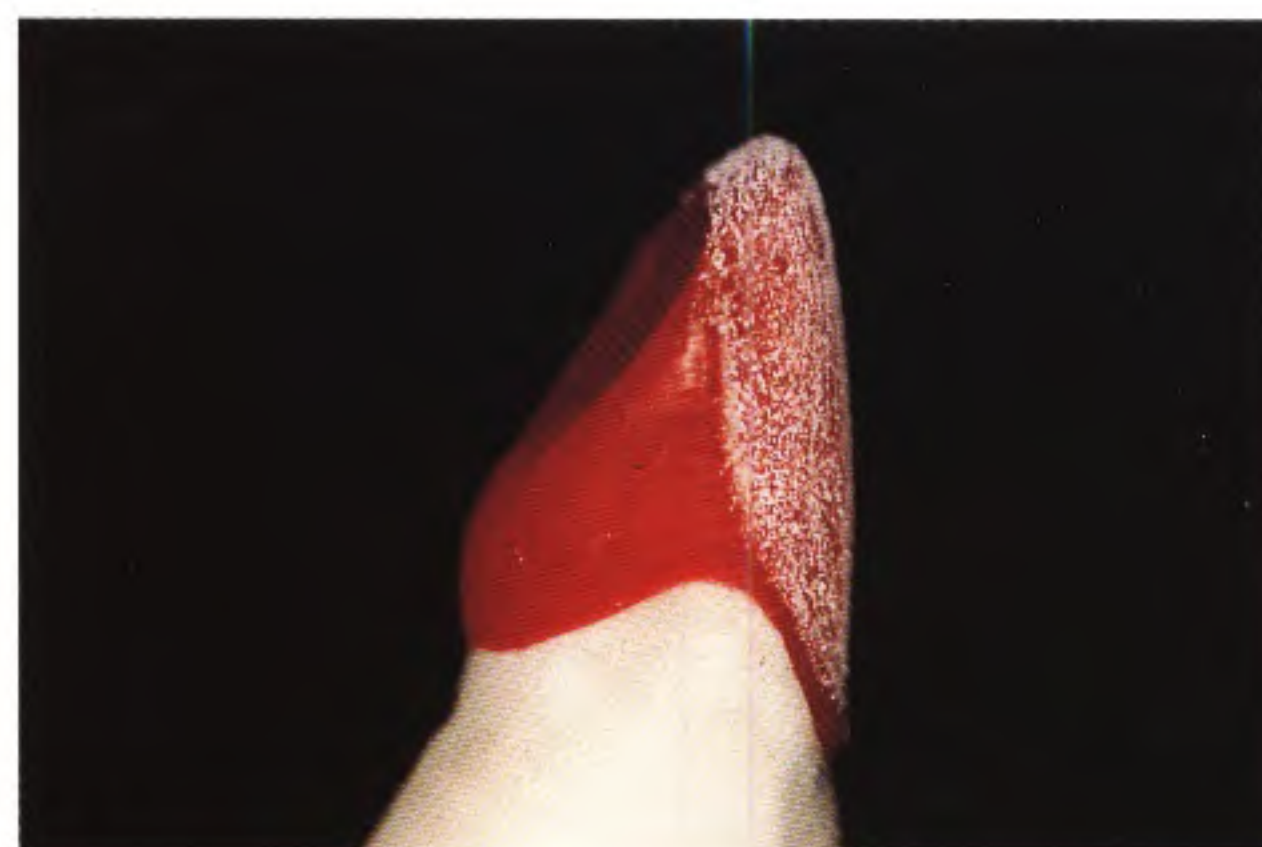


Fig 4-21 Redefine the porcelain-metal junction until it is sharp, continuous, and well defined. The wax should form a 90-degree external line angle at the junction line. At this point the full-contour waxup technique has accomplished two objectives considered vital to the success of the completed metal ceramic restoration. First, and perhaps more important, is the formation of an even thickness of the cutback. Second, the crown contours at the porcelain-metal junction are continuous and anatomically correct.

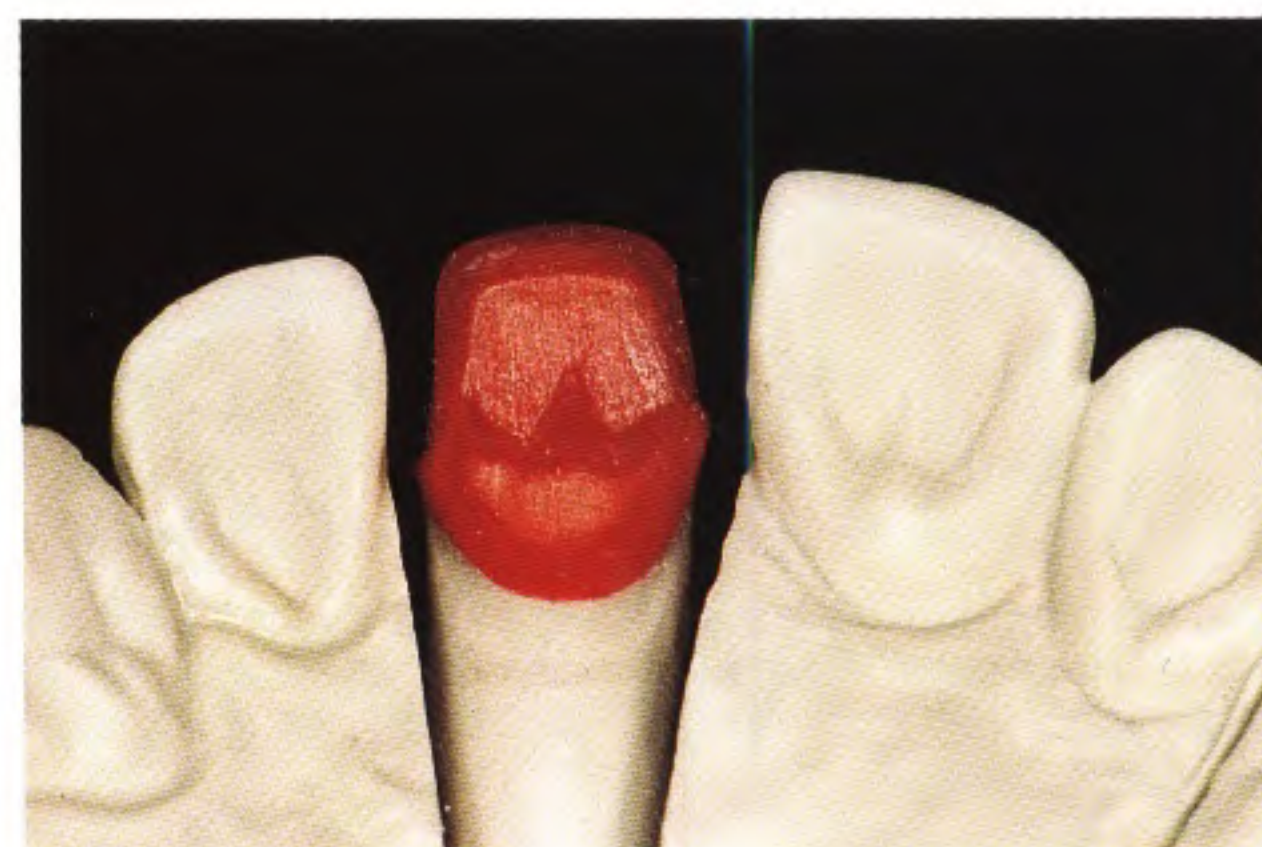


Fig 4-22 The anterior substructure design illustrated in Fig 4-7, B is a blend of both designs 4-7, A and 4-7, C, because it retains most of the metal on the lingual surface yet permits restoration of the interproximal areas in porcelain.

Fig 4-23 When an accurate full-contoured waxup has not been used, it is not uncommon to produce unwanted changes in contour (*arrow*) for either the porcelain or the metal in the area of the porcelain-metal junction. (Courtesy of J. C. Kessler, DDS.)

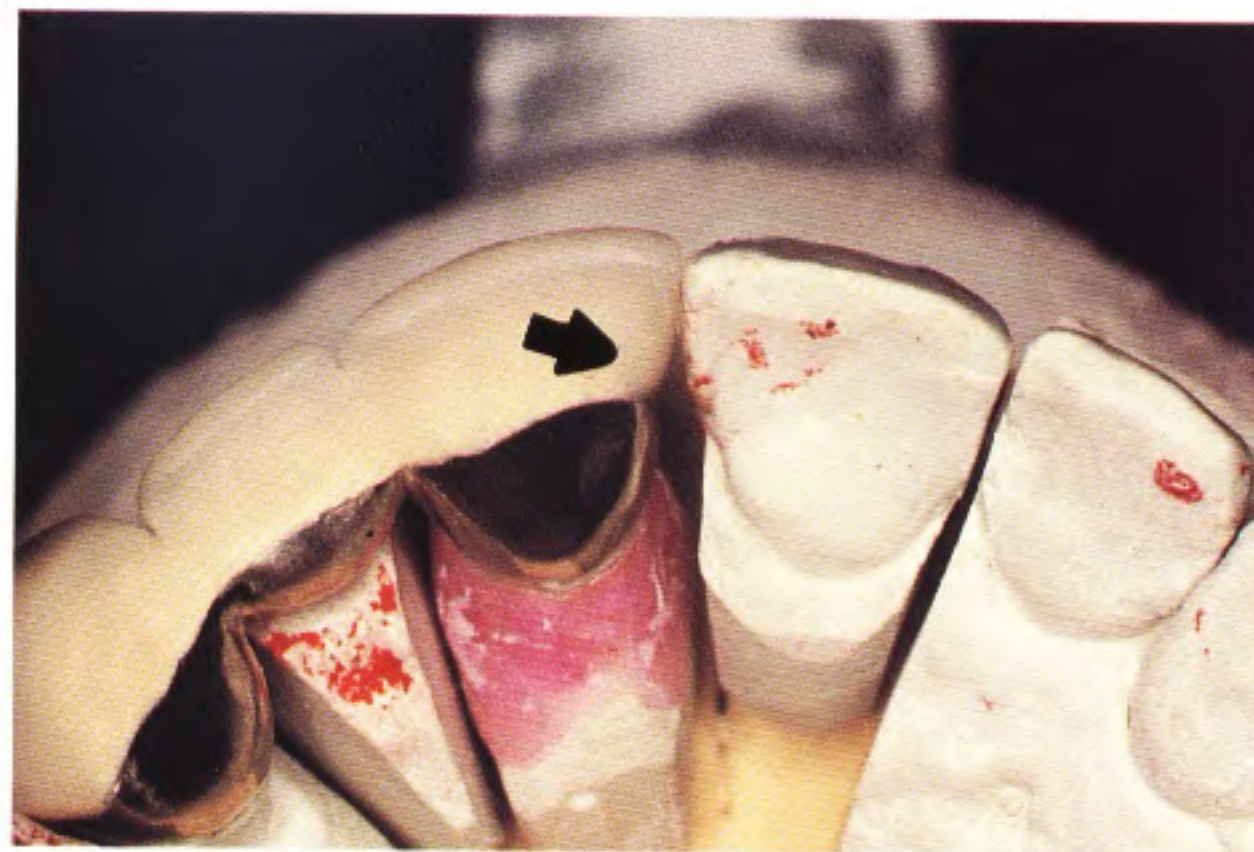


Fig 4-24 The porcelain may even overlap the porcelain-metal junction in order to restore proper contour. Obviously, these thin projections of porcelain that extend onto the metal will be fragile and more readily prone to fracture. (Courtesy of J.C. Kessler, DDS.)

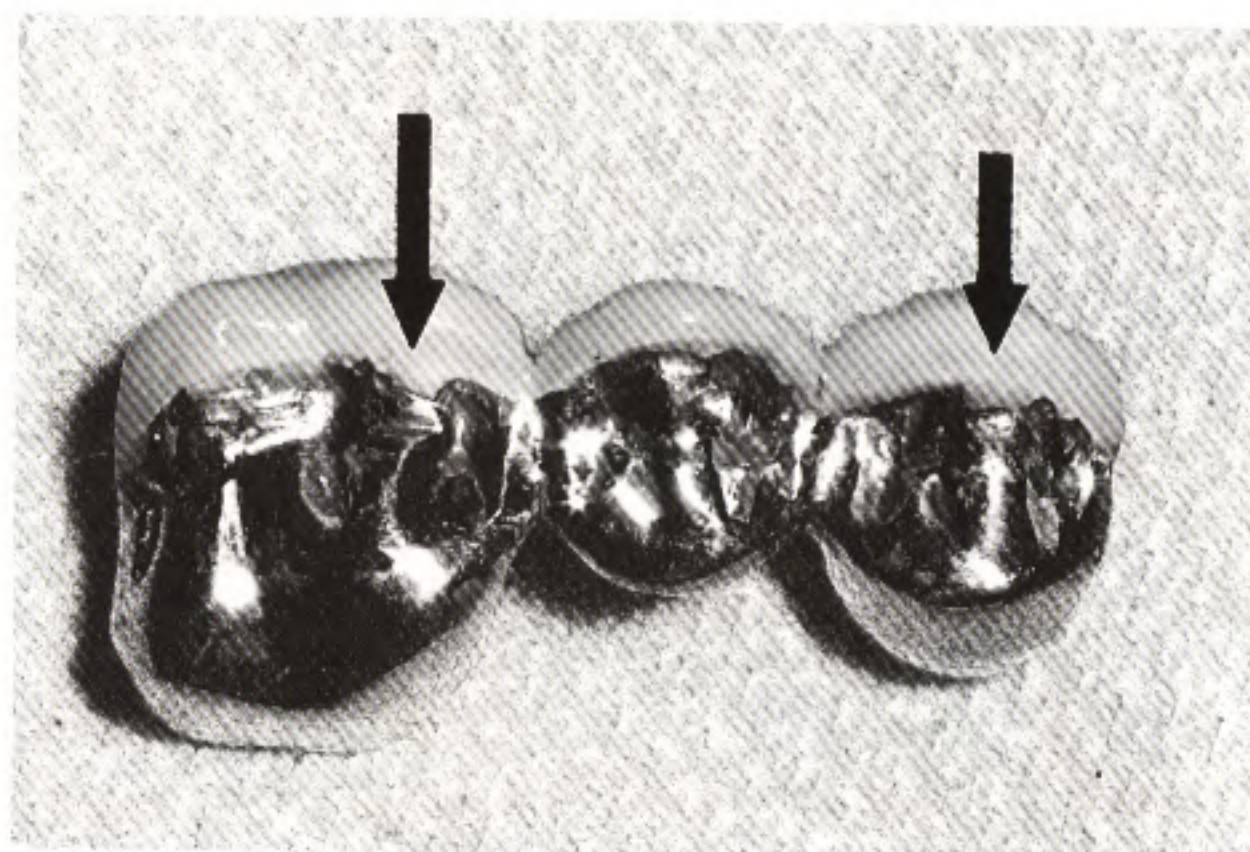


Fig 4-25 Seal the margins of the completed wax pattern carefully; use a microscope or other form of magnification.



Fig 4-26 You may wish to add a 2-mm-long piece of 18-gauge wax to the lingual collar to serve as a working handle before the wax sprue former is luted to the substructure. Once cast, this metal extension will permit you to grasp the cast restoration without fear of damaging the delicate metal margins. Invest the completed pattern as soon as possible after completing the waxup.

Maxillary anterior substructures with a porcelain lingual surface (Figs 4-27 to 4-30)

The technique for fabricating an anterior metal ceramic crown substructure with the lingual surface restored in porcelain (Fig 4-27) is virtually the same as that presented in Figs 4-9 to 4-26. The major difference is the extent of the cutback; all other procedures are the same.

Procedures for maxillary posterior substructure design

The substructure construction for maxillary posterior teeth is accomplished according to the same design principles previously outlined. However, you often have more freedom with the final substructure design, because esthetic requirements for posterior teeth are often less stringent. The basic design options are illustrated in Fig 4-31.

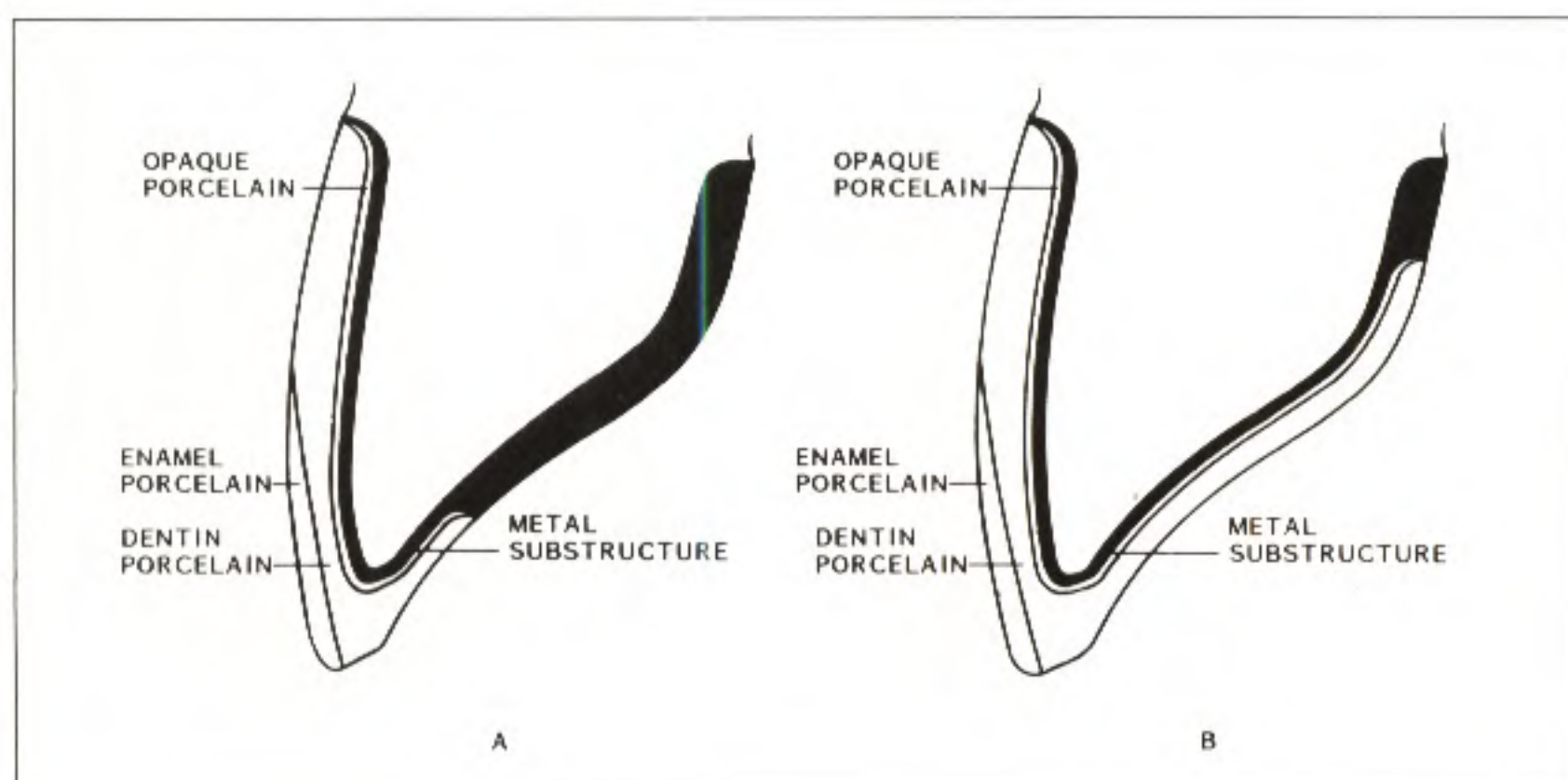


Fig 4-27 Prepare a substructure design like that depicted in Fig 4-7, A. The basic difference between an anterior metal ceramic restoration with a metal lingual surface (A) and one with a porcelain lingual surface (B) is the extent of the porcelain coverage and the height of the lingual metal collar.



Fig 4-28 Cut back the facial surface of the wax pattern with the same technique illustrated in Figs 4-9 to 4-20 but extend the location of the porcelain-metal junction cervical to the occlusal contacts on the lingual surface.

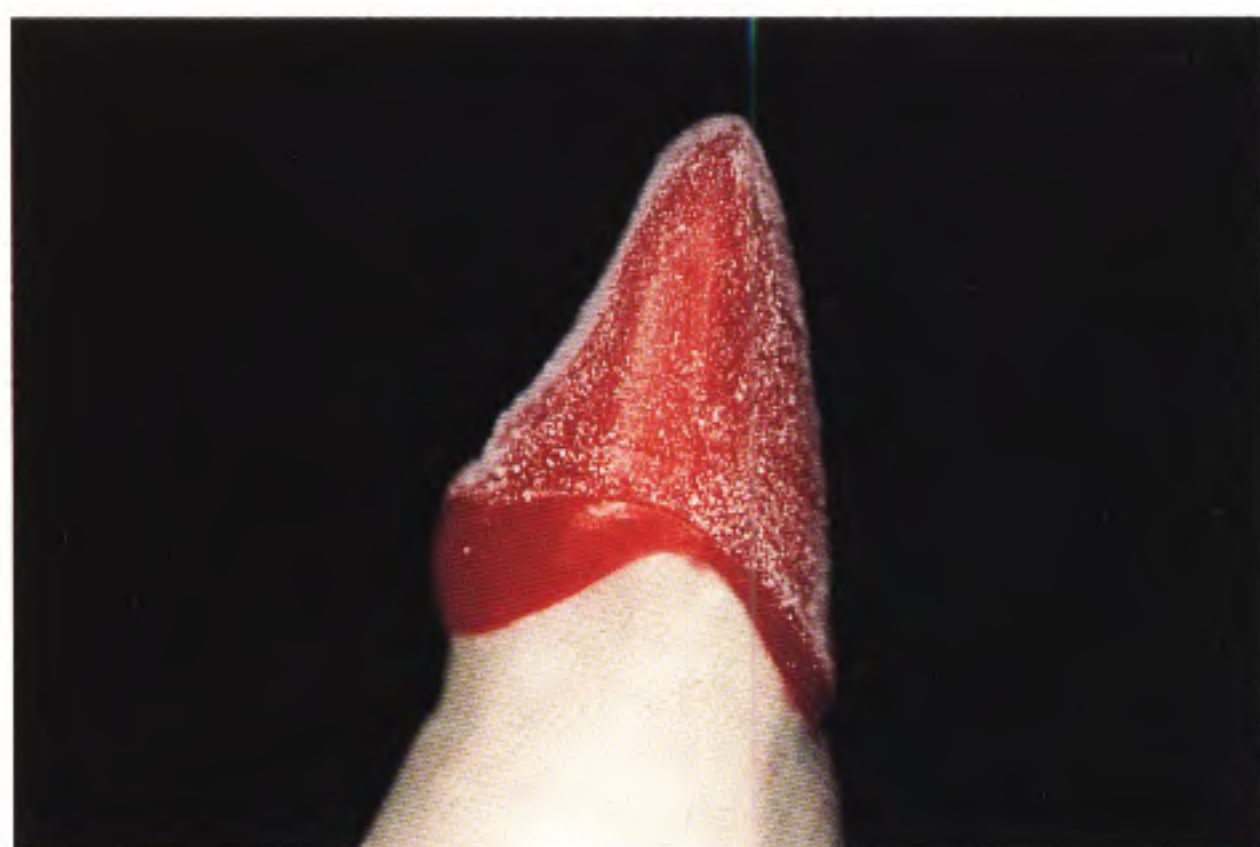


Fig 4-29 Leave at least 2 mm of metal in the midlingual area to provide rigidity to the substructure and smooth the entire wax pattern. The wider lingual collar can be tapered through the interproximal area and blended with the facial metal collar.



Fig 4-30 Lute an 18-gauge sprue former to the lingual collar and attach the wax sprue former in preparation for investing.

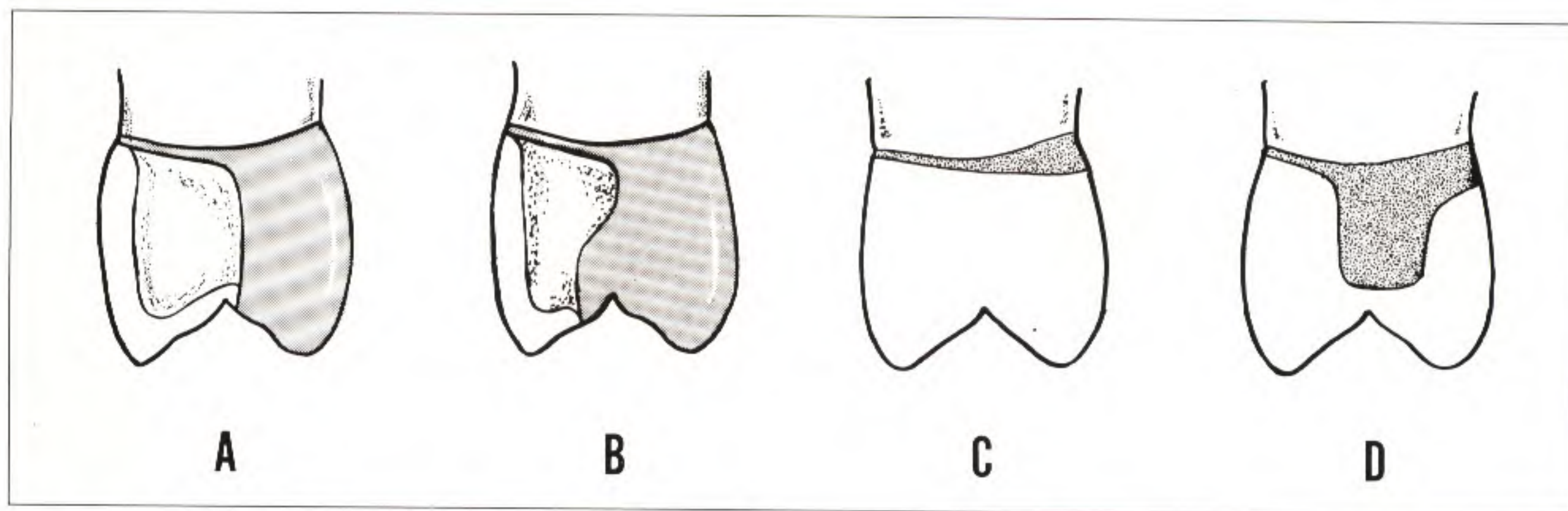


Fig 4-31 Basic design options for maxillary posterior substructures. Substructures with occlusal surfaces in metal but interproximal contacts in porcelain (A) and metal (B) and substructures with porcelain occlusal surfaces without (C) and with (D) interproximal support.



Fig 4-32 Wax the restoration to full contour and assess its contours from occlusal and facial views. Dust the pattern with powdered wax and locate the areas of occlusal contacts. Scribe a line on the inner incline of the buccal cusp from distal to mesial that is 2 mm from any area of occlusal contact.



Fig 4-33 Scribe the gingival and interproximal lines for the proposed cutback. Remove the die and wax pattern from the master cast and connect the occlusal and interproximal scribe lines for the cutback.



Fig 4-34 Complete the cutback with the technique described previously, then view the completed wax pattern from occlusal and facial views.

As with anterior restorations, the crown is waxed to full contour and the desired occlusion. How the waxup will be completed, of course, depends on whether the occlusal surface is to be restored in metal or porcelain. A full-contour waxup is needed so that the exact location of the occlusal contacts and the cusp-fossa contours can be established and evaluated. If the occlusal surface is to be maintained in metal, the occlusion should be finalized in the full contour waxup. If the final restoration is to have full porcelain occlusal coverage, the occlusion will not be finalized in wax but developed in the porcelain veneer. Determining an appropriate occlusal relationship is vital and will ensure a proper cutback as well as a uniform thickness of porcelain for the final restoration.

Regardless of which restorative material is chosen for the occlusal table, you should analyze the preparation clearance with the opposing teeth in centric



Fig 4-35 Carefully examine the cutback to make certain enough wax has been removed to ensure that the ceramic veneer will be uniform in all areas. If the interproximal contact area is to be restored in porcelain (A) rather than metal (B), extend the cutback of the porcelain-metal junction further lingually. (Compare to Fig 4-31.)

occlusion and all excursive movements. Check the right and left lateral excursions as well as the protrusive (anterior) jaw movement. Remember, if a restoration with a porcelain occlusal surface is to have satisfactory esthetics and proper contours, a minimum tooth reduction of 1.5 to 2 mm must be possible.

Maxillary posterior substructures with a metal occlusal surface (Figs 4-31 to 4-35)

Whether it is because esthetic concerns are less critical or because minimal tooth reduction is possible, there are cases that lend themselves to restoring the occlusal surface in metal. The technique is similar to those described for anterior restorations.

Maxillary posterior substructures with a porcelain occlusal surface (Figs 4-31 and 4-36 to 4-38)

Esthetic requirements may necessitate the restora-

tion of occlusal surfaces in dental porcelain rather than metal. For these cases, the substructure is designed much like an anterior restoration with a porcelain lingual surface. The principal requirement is sufficient tooth reduction to provide adequate interarch and intraarch clearances that will accommodate the thickness of the metal substructure and the porcelain veneer.

First, wax the restoration to full contour to reproduce the appropriate axial contours. Then select the type of substructure most appropriate for the particular clinical case (Fig 4-31, C or D) and continue with the steps outlined in Figs 4-36 to 4-38.



Figs 4-36a and b The extent of the wax cutback will depend on the occlusal-lingual height of the tooth being restored and the esthetic requirements for restoring the interproximal area. Support the marginal ridge by retaining metal in the interproximal (*left*) and lingual (*right*) areas.

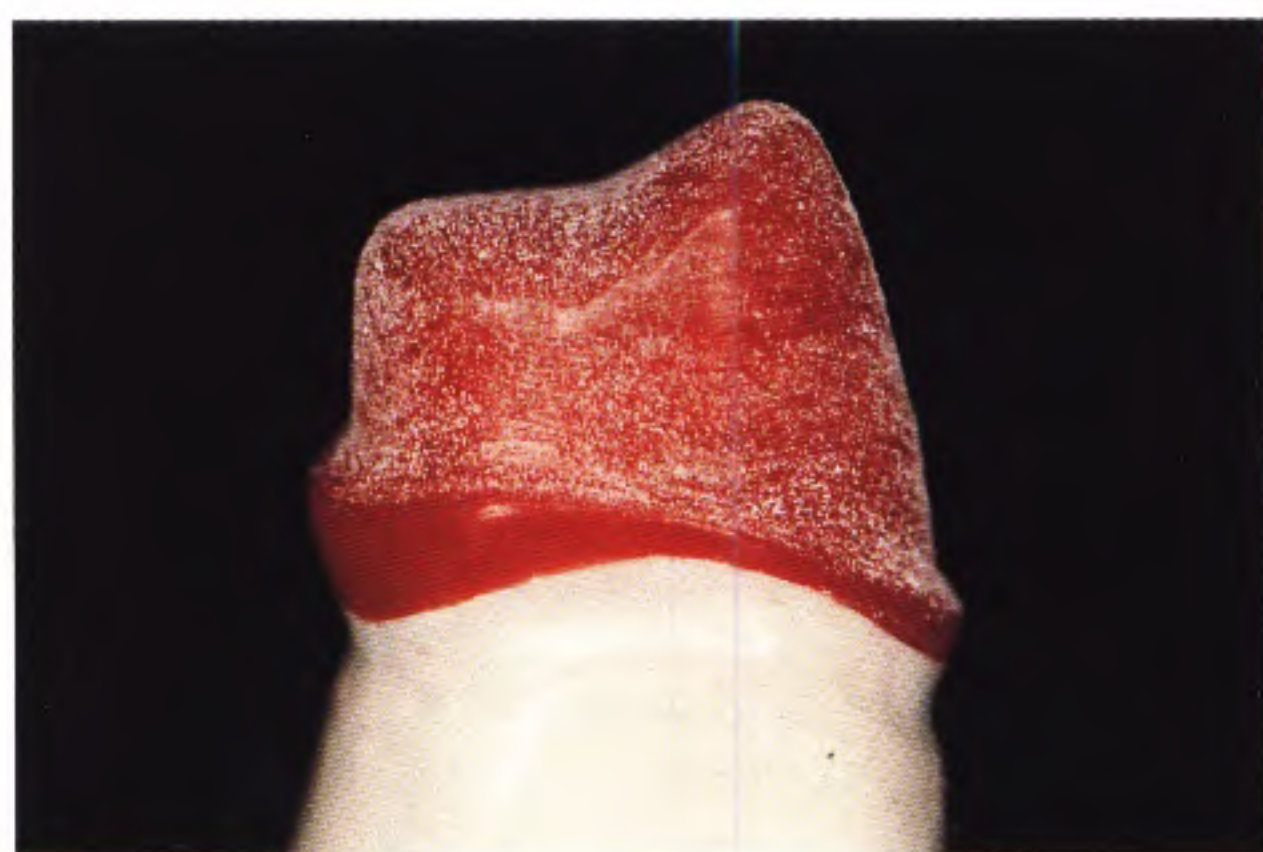


Fig 4-37 Or, cutback the interproximal area (as shown in Fig 4-31, C), creating a 2-mm collar on the lingual with a narrowing through the interproximal area to the facial metal collar.



Fig 4-38 Examine the completed wax pattern from all views (occlusal, lingual, and interproximal) to make certain the cutback is correct and the wax pattern is smooth. Lute an 18-gauge wax sprue former to the middle of the lingual collar to facilitate handling of the restoration once the substructure has been cast. Attach a wax sprue former to the completed pattern. Make certain the transition from sprue former to wax pattern is smooth and without irregularities.

Mandibular anterior substructure designs

The mandibular anterior teeth present almost no options if they are present in a normal Class I occlusal relationship in terms of horizontal and vertical overlap. Esthetic demands necessitate restoration of the incisal, labial, and interproximal surfaces in porcelain with a lingual collar of metal. In situations where lingual tooth reduction has been minimal, that surface may be readily restored with an adequate thickness of metal. However, overlap of the porcelain onto the incisal-lingual surface is recommended for strength.

Vital, mandibular anterior teeth may also be restored with noncast metal ceramic substructures such as Renaissance (Williams Dental Company) and Sunrise (Tanaka Dental Company) crown systems. With these two products, a high noble metal foil is adapted directly on the gypsum die to produce an ultrathin substructure that can be opaqued and veneered with a greater bulk of metal ceramic porcelain (Coffield, 1988).

The preformed metal substructures in the Renaissance Crown system have a high noble metal content and will not oxidize. Therefore, an interfacial bonding agent is applied and fired to the adapted coping. Opaque and body porcelains are fired over the layer of interfacial alloy as the crown is built to full contour.

In the Sunrise System, a noble metal foil is also used but no interfacial alloy or bonding agent is placed on the metal coping, so opaque and body porcelain are applied and sintered directly on the metal.

Mandibular posterior substructure designs

Mandibular posterior teeth are not always visible in normal function and speech; therefore, it may not be necessary to restore them with metal ceramic restorations. From a purely functional point of view, these teeth can be adequately restored with complete metal crowns. Yet patient and clinician preferences vary enormously, and it is not uncommon to receive requests to restore mandibular first molars, and on occasion mandibular second molars, with metal ceramic crowns.

Four basic substructure designs that can be used for the mandibular posterior region are illustrated in Fig 4-39. These are only basic design options; the actual configuration created may be modified to meet the specific and unique occlusal and esthetic requirements of each particular patient.

Unfortunately, the full-porcelain occlusal design is often prescribed for an underprepared or otherwise

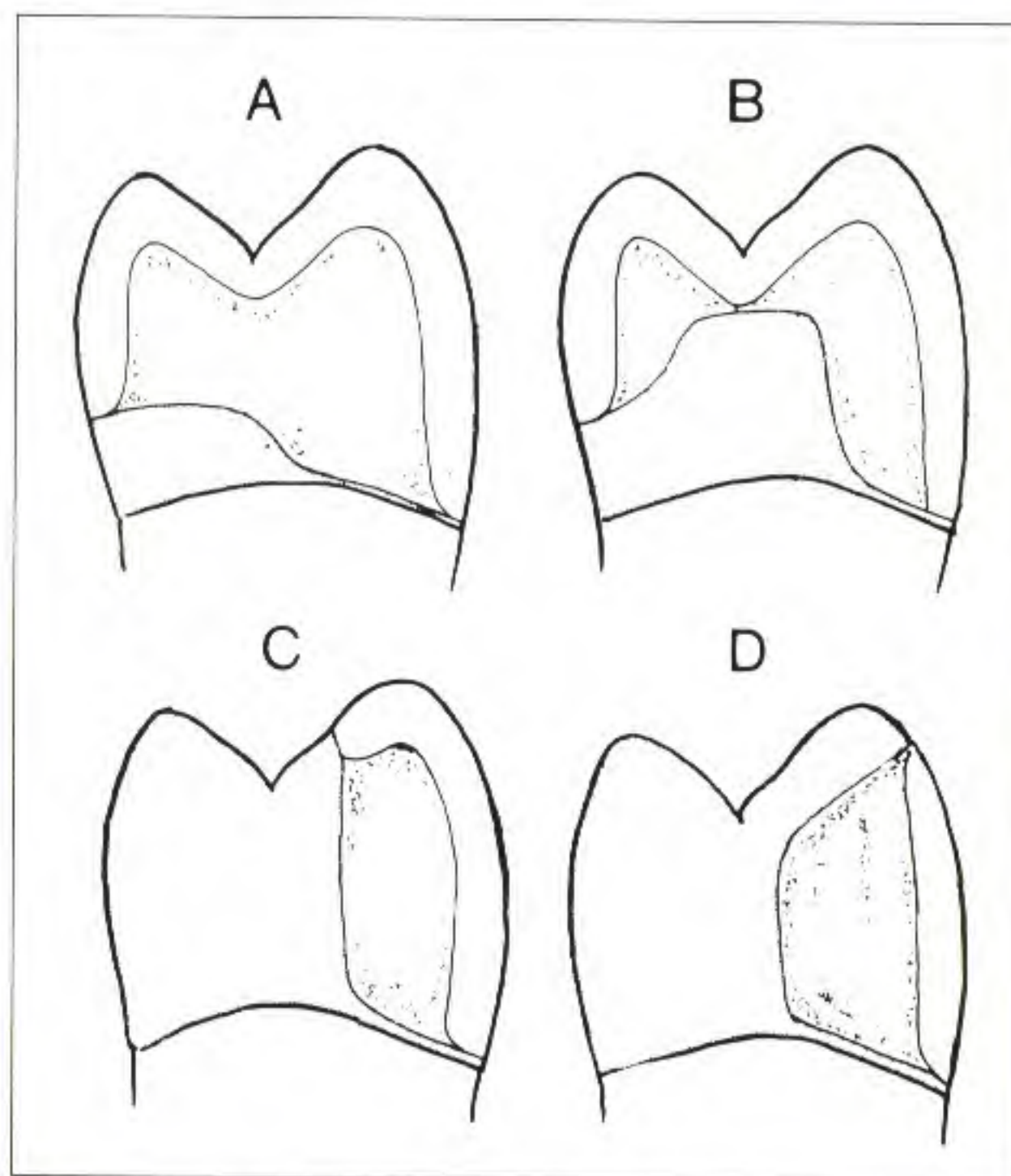


Fig 4-39 Four basic substructure designs for the mandibular posterior region.

poorly suited clinical situation. The net result is an overly adjusted restoration or opposing tooth. In either case, the error occurred at diagnosis or again at the time of tooth preparation with a failure to obtain the requisite 1.5- to 2-mm occlusal clearance.

Short clinical crowns, which are not uncommon with mandibular posterior teeth, are more ideally suited for restorations with metal occlusal surfaces. Full-porcelain restorations quickly become esthetically compromised when large areas of opaque or metal are exposed (or nearly exposed) as a result of extensive occlusal adjustment resulting from a lack of interocclusal space.

Fixed partial dentures

The same basic principles and design considerations used in fabricating a single-unit metal coping can be applied when planning the substructure for a metal ceramic fixed partial denture. However, there are several technical issues to be dealt with before casting a multiple-unit substructure. For instance, will the prosthesis be cast in one piece or in sections? If you choose to make a two-piece casting, you must also decide whether the framework will be pre- or post-

soldered. If you chose presoldering, then you must consider the location of the solder connector(s). For example, will the connector(s) be located interproximally or diagonally through a pontic? The very design of the substructure in the connector areas must allow for the location of the solder joints.

All of these issues are important determinants in the fabrication of a fixed prosthesis; however, the basic concepts discussed here are applicable whether the substructure is cast as a single unit or multiple units and soldered. More extensive discussion of connector and pontic design can be found in such references as Riley (1977), Shillingburg et al (1981), and Yamamoto (1985).

Anterior fixed partial denture substructure designs

Figure 4-40 illustrates a basic design for the anterior pontic, referred to as a modified ridge lap (Fowler and Tamura, 1987; Malone and Koth, 1989; Rosenstiel et al, 1988). This configuration is often favored in the replacement of missing anterior teeth because the design allows for maximum esthetics by virtue of the labial extension of the pontic and permits proper cleaning of the convex lingual and gingival contours of the prosthesis (Shillingburg et al, 1981). Note how this well-designed pontic substructure permits a uniform thickness of porcelain. This is true even in the gingival region of the pontic where the cervical one third of the pontic is composed of porcelain and the porcelain-metal junction is located well away from the soft tissue of the edentulous ridge. Even though care was exercised during the finishing and polishing procedures, the junction of the porcelain and metal is a potential source of roughness and tissue irritation. It would obviously be esthetically unacceptable to extend the metal substructure onto the labial aspect of the gingival portion of the pontic. The logical alternative is to place all tissue contact in porcelain. It has also been shown that highly glazed porcelain is more resistant to plaque accumulation than metal, which would be an additional advantage to this type of pontic design (Chan and Weber, 1986; Stein and Kuwata, 1977).

The same general design considerations for the location of occlusal contacts and lingual contour with single-unit restorations would apply to the design of retainers for a fixed partial denture.

Procedures for an anterior fixed partial denture

An accurate full-contoured waxup is even more critical for a fixed partial denture than for a single-unit

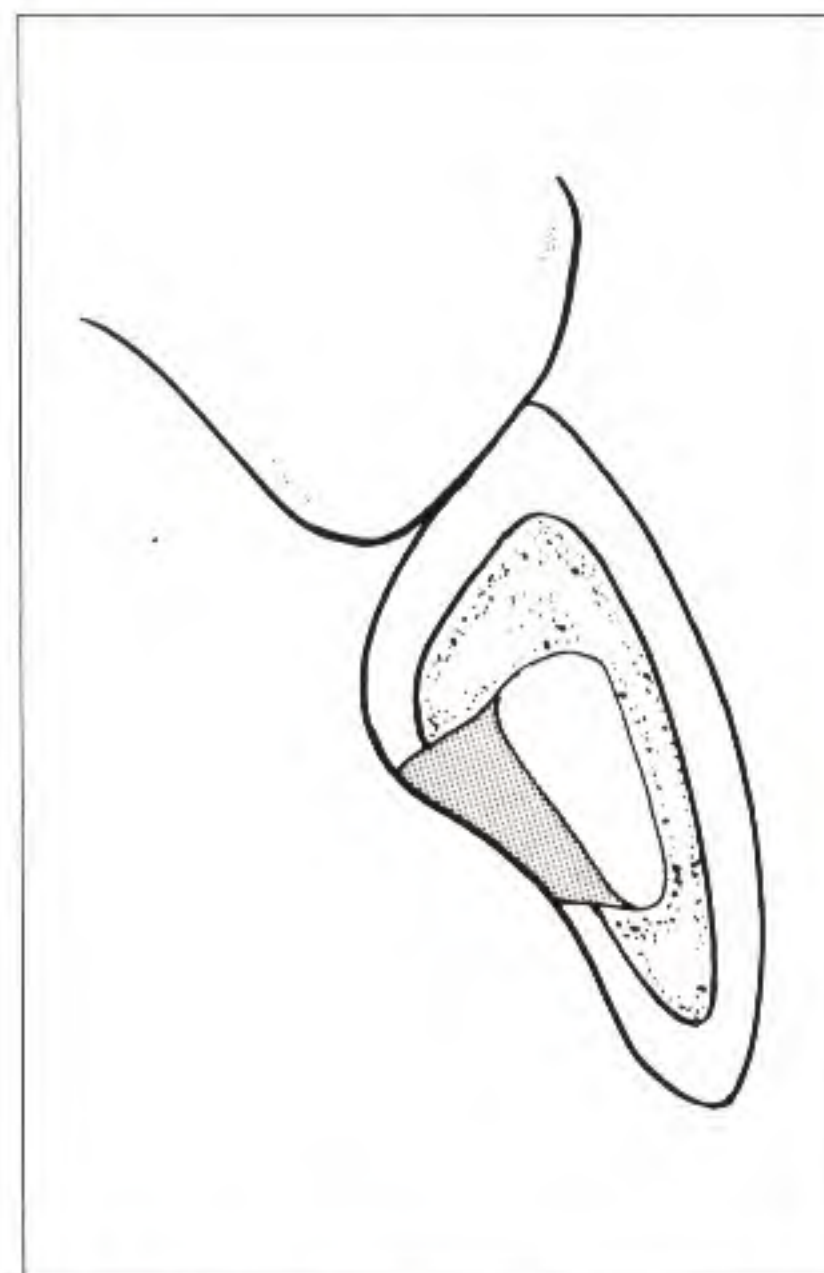


Fig 4-40 A modified ridge lap design for the anterior pontic.

restoration. The occlusal scheme should be finalized in centric occlusion and all excursions (left lateral, right lateral, and protrusive movements). The size and position of the pontic(s) need to be established in wax, because it is far easier to make contour adjustments in wax than either in porcelain or metal. Moreover, the position and size of the interproximal connectors and their accompanying labial, incisal, and gingival embrasures can be evaluated. The following steps can serve as helpful guides to proper anterior fixed partial denture fabrication.

In framework design, it is important to understand that the degree of deformation of the metal is proportional to the cube of the length (Riley, 1977). When the length of the fixed partial denture is doubled and the load and number of retainers remain constant, the degree of deflection increases by a factor of eight. Even more significant is the fact that if the span (number of pontics) of the prosthesis is increased three times and the load remains the same, the amount of flexure will be 27 times as great (Riley, 1977). Consequently, an increase in the length of the span of a fixed partial denture will have a profound effect on the stresses placed on the interproximal connectors. Also, significant consequences occur when the proper connector dimensions are compromised. If the occlusal-gingival thickness of a given connector is reduced by one half, the resulting deflec-



Fig 4-41 Carefully inspect the fixed partial denture waxed to full contour to ensure that it has the proper contours and outline form sought in a fixed restoration.



Fig 4-42 (left) After the occlusion is marked, scribe a line on the lingual surfaces of the waxup to indicate the location of the porcelain-metal junction. Place a scribe line on the facial surface to indicate the extent of the incisal cutback. Connect the facial and lingual scribe lines in the interproximal areas as done previously with the anterior single-unit restoration (see Fig 4-33). Cut back the incisal edges.

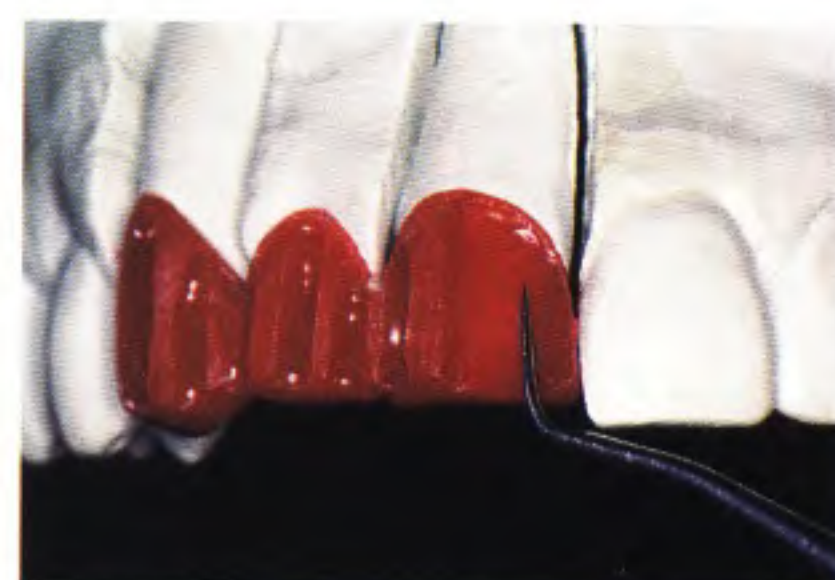


Fig 4-43 (right) Place depth cuts in each unit and perform the facial cutback.



Fig 4-44 Refine the lingual surfaces with a carving instrument so the porcelain-metal junctions are sharp and distinct.



Fig 4-45 After the cutback, view the substructure from the facial, incisal, and lingual views. Note the removal of 1 mm of wax from the tissue side of the pontic to permit that area to be restored in porcelain. You can now attach sprue formers to the completed wax pattern along with a piece of 18-gauge wax to each retainer pattern.

tion will be eight times as great. This is particularly important with long-span posterior fixed partial dentures.

Follow the steps outlined in Figs 4-41 to 4-45.

Posterior fixed partial denture substructure designs

A posterior fixed partial denture substructure essen-

tially is fabricated according to the same design principles used for single-unit posterior restorations. Two basic pontic designs are illustrated in Fig 4-46. As with the anterior fixed partial denture, the most widely used design to replace missing posterior teeth is the modified ridge-lap pontic (Fig 4-46, A). An alternative design commonly used with metal ceramic restorations is the conical configuration (Fig 4-46, B); this is usually restricted for use in the less visible areas of mandibular posterior restorations.

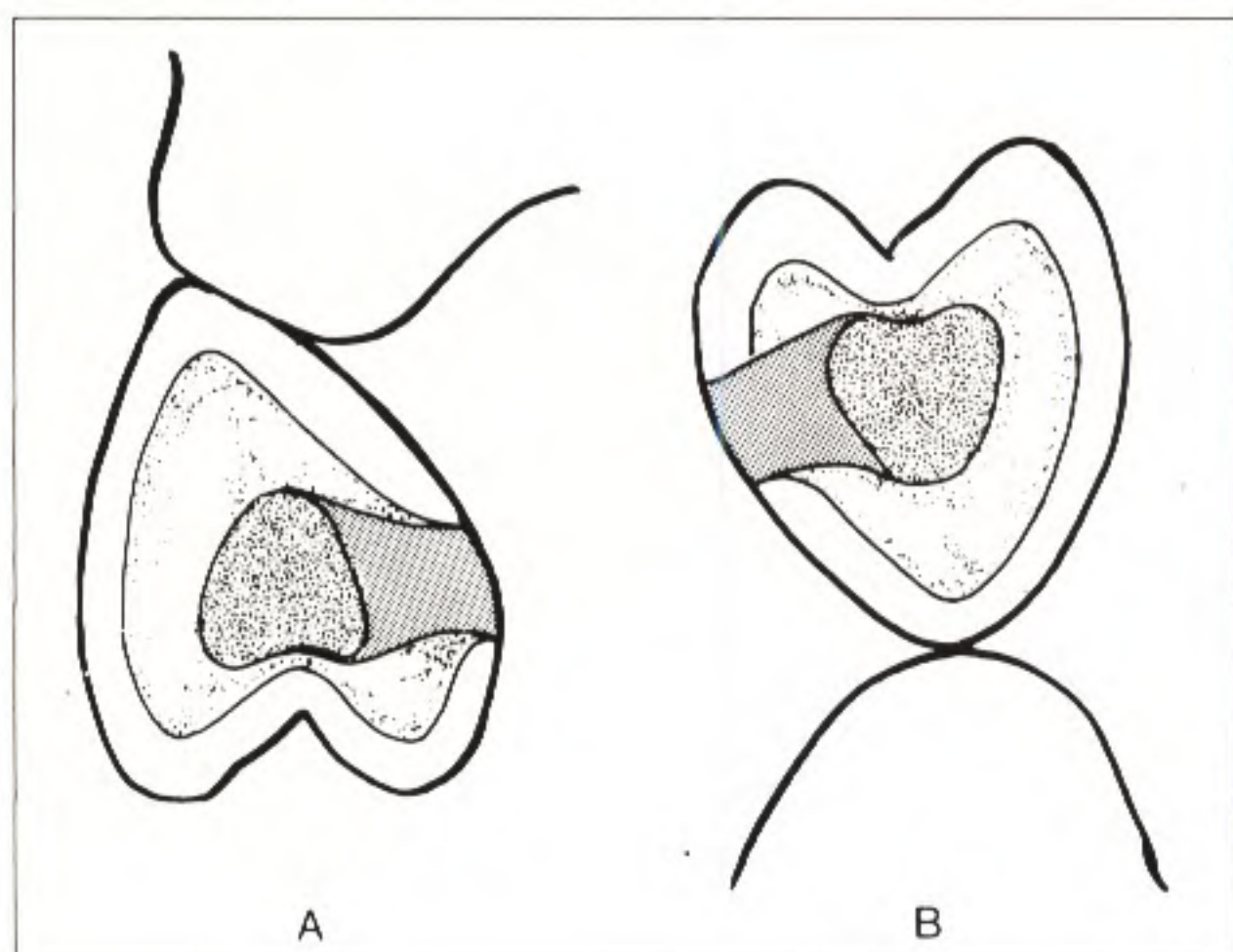


Fig 4-46 (A) The most widely used design to replace missing posterior teeth is the modified ridge-lap pontic. (B) The conical configuration is an alternative design commonly used with metal ceramic restorations.

Designing the interproximal areas of substructures

The third principle of substructure design requires a determination of the restorative material for the interproximal contact areas: metal or porcelain. However, the designs for anterior and posterior substructures provide only approximate locations for the porcelain-metal junction in the interproximal areas (see Figs 4-12, 4-21, 4-33, and 4-35).

The design of the interproximal porcelain-metal

junction in the final restoration depends on the location of the interproximal contact areas and whether these areas are to be restored in porcelain or metal (Figs 4-47 and 4-48). You should know the location of these interproximal contact areas for the maxillary arches (Fig 4-49a, bold lines) and the mandibular arches (Fig 4-49b, bold lines) (Wheeler, 1974). After you identify the correct facial-lingual location of the interproximal contact areas decide if you want to retain that contact in metal or porcelain (see Fig 4-47). If you opt to use porcelain, simply move the porcelain-metal junction until it is just lingual to that area (see Fig 4-48).

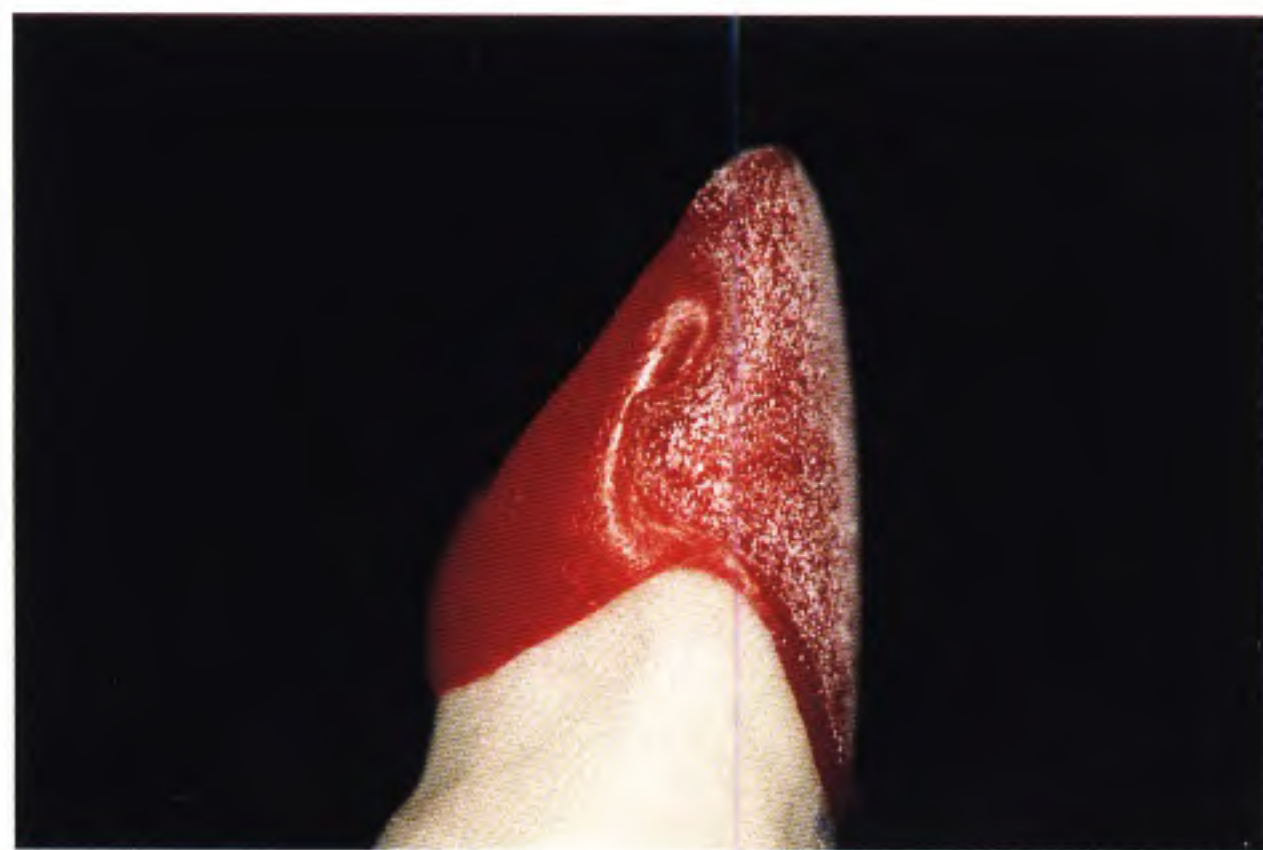


Fig 4-47 If you wish to restore the interproximal contacts in metal, the porcelain-metal junction line will lie facial to the contact area, as illustrated in Fig 4-18. But if you wish to retain metal contacts but also want to maximize the extension of porcelain into the interproximal areas, you can create a scalloped effect by removing the wax *below* and *lingual* to the contact area.

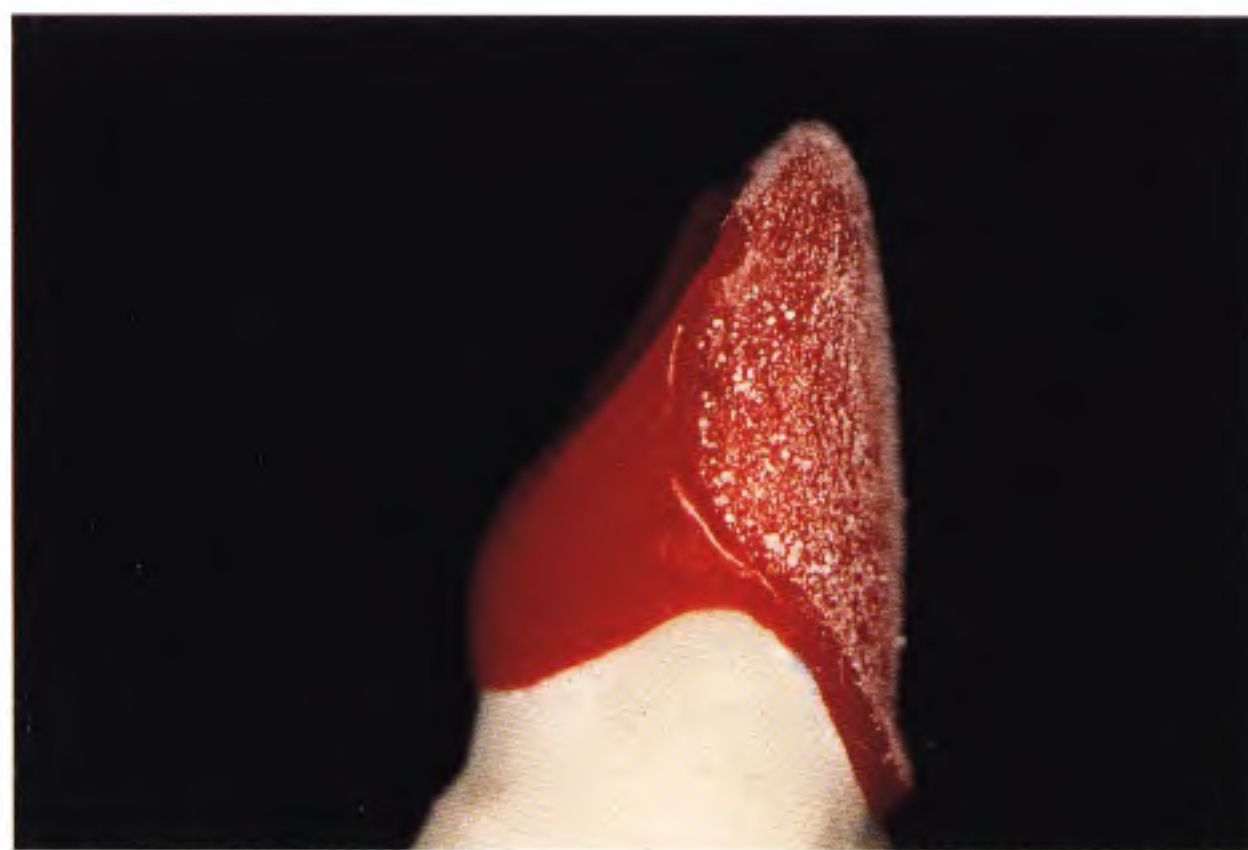


Fig 4-48 To retain the lingual surface in metal but restore the interproximal contacts in porcelain, simply move the porcelain-metal junction *lingual* to the contact area. Of course when you choose a substructure with a porcelain lingual surface, the interproximal areas will have to be restored in porcelain.

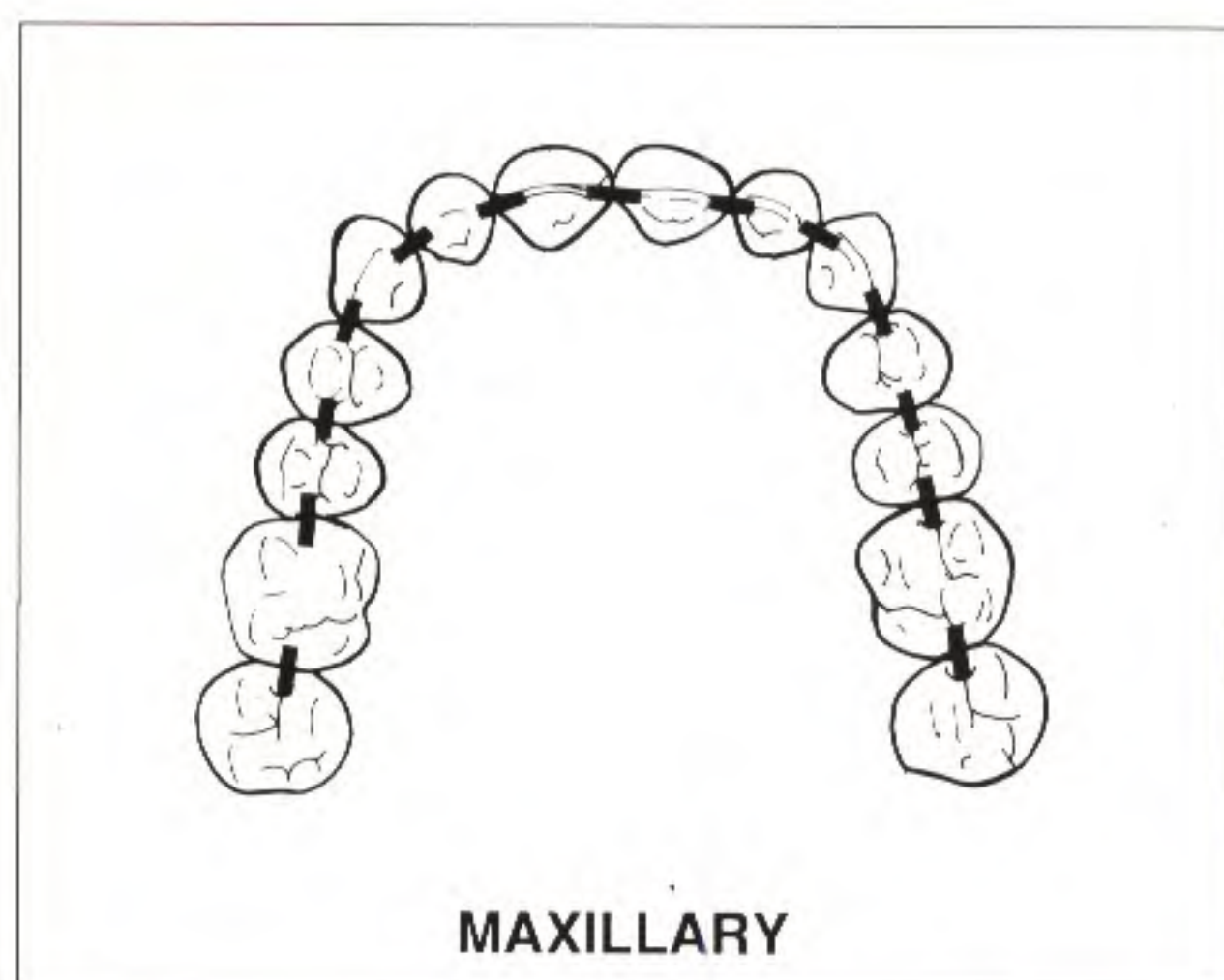


Fig 4-49a Location of interproximal contacts (*bold lines*) for the maxillary arch.

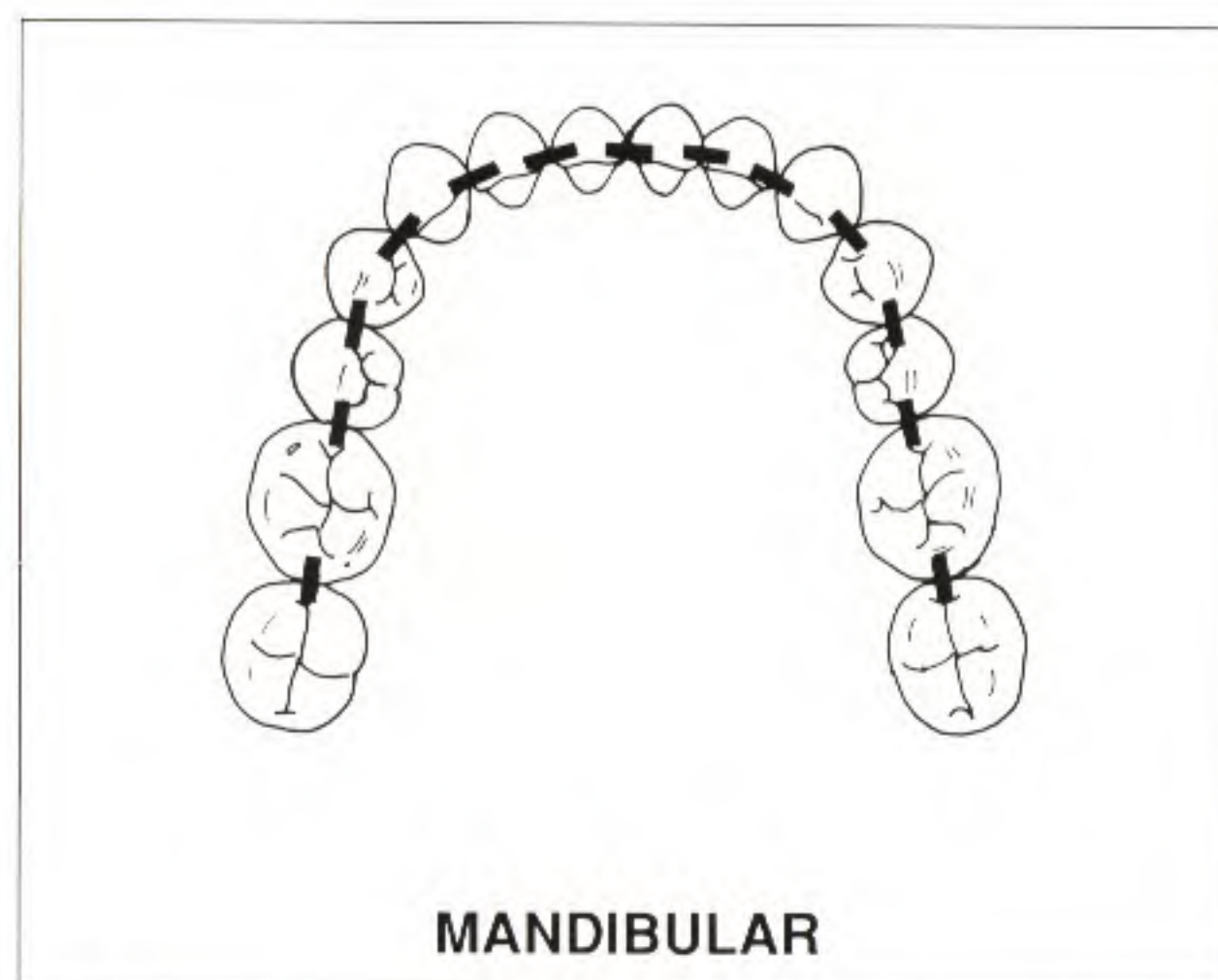


Fig 4-49b Location of interproximal contact areas (*bold lines*) for the mandibular arch.

Margin designs for metal ceramic restorations

The dentist should select the proper margin design at the time of tooth preparation so that he or she can prepare a finish line appropriate for the particular case at hand. The design of the labial margin of a metal ceramic restoration is then finalized during the waxup and margination of the wax pattern.

Representative examples of the major finish line designs and the margins that are produced by each are illustrated and described below.

A 90-degree or square shoulder-bevel finish line (Fig 4-50)

Any finish line preparation that includes a bevel should be accompanied by a restoration with a collar of exposed metal at least as wide as the bevel itself. When a bevel is present, attempts to cover all the exposed metal with porcelain invariably result in an overcontoured restoration. Obviously, this exposed metal collar can present an unacceptable esthetic appearance in some situations. Even slight overcontouring in the gingival 1 or 2 mm of a restoration will almost always create an adverse marginal tissue response (Fig 4-51). The 90-degree internal line angle is believed to provide internal buttressing of the shoulder margin (Preston, 1977).

If the shoulder is angled more than 90 degrees, the finish line design is then referred to as a slant shoulder.

Rounded shoulder or deep chamfer finish line (Fig 4-52)

This is the same design as the 90-degree or square shoulder-bevel finish line except that the internal (axial-lingual) line angle is rounded. It too can be prepared with or without a bevel. If the shoulder is slanted more than 90 degrees, it can also be called a slant shoulder finish line.

Chamfer finish line (Fig 4-53)

This finish line design allows you to feather the metal at the labial margin so only a minimal amount of exposed metal margin is present in the completed crown. When meticulous attention is paid to waxing, metal finishing, and porcelain application, the result can be an esthetically acceptable restoration even in demanding clinical situations.

A 90-degree (or square shoulder) finish line (Fig 4-54)

Although the labial margin in this metal ceramic restoration design will probably be constructed with porcelain, a properly designed substructure is still essential. The finish line for the labial surface should be a shoulder approximately 1 mm wide. The junction of the shoulder and the axial wall of the preparation generally is a well-defined line angle of 90 degrees

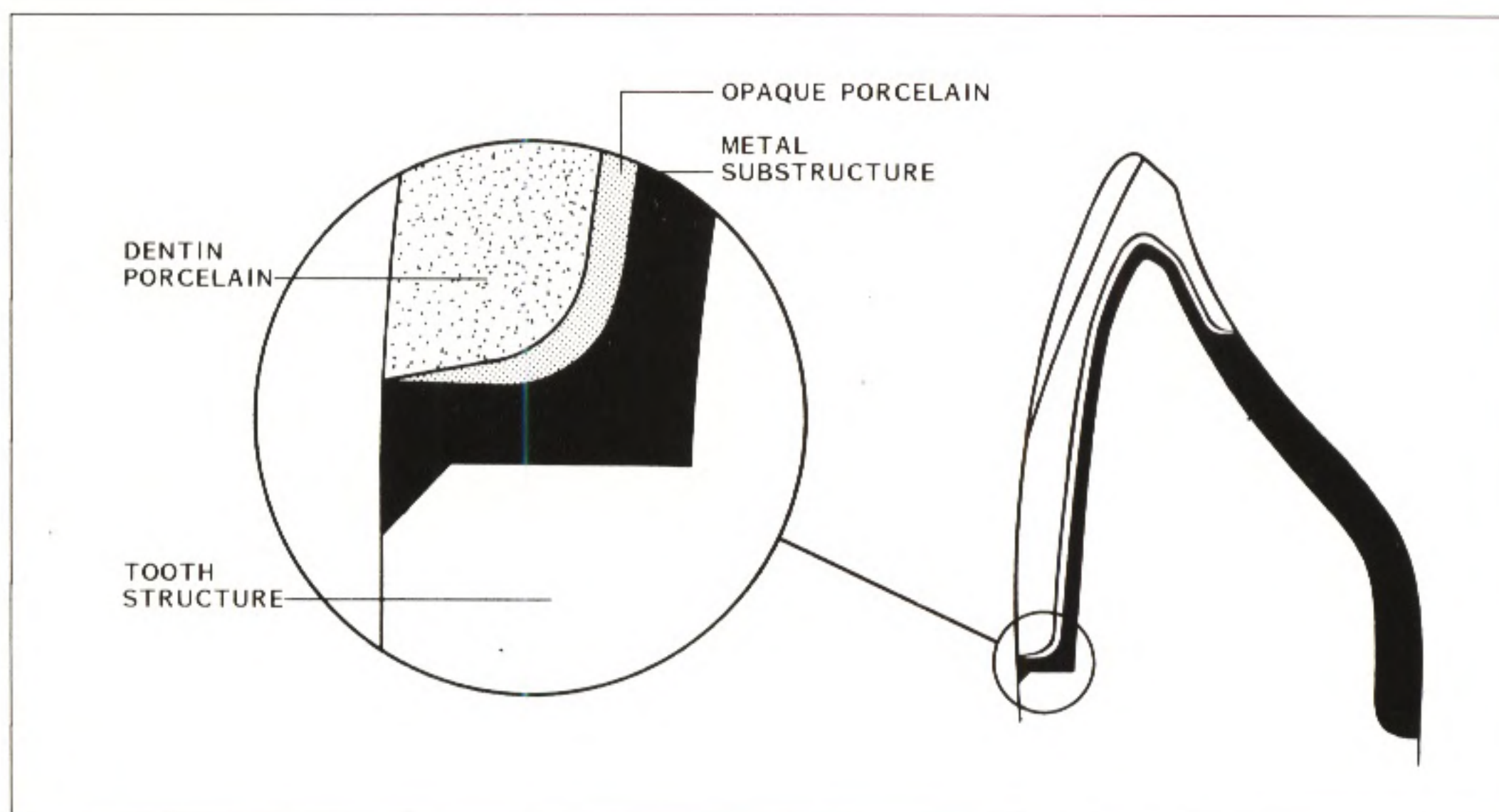


Fig 4-50 A 90-degree (or square shoulder) bevel finish line. Note that the collar of exposed metal should be at least as wide as the bevel itself.



Fig 4-51 Note adverse marginal tissue response created by slight overcontouring.

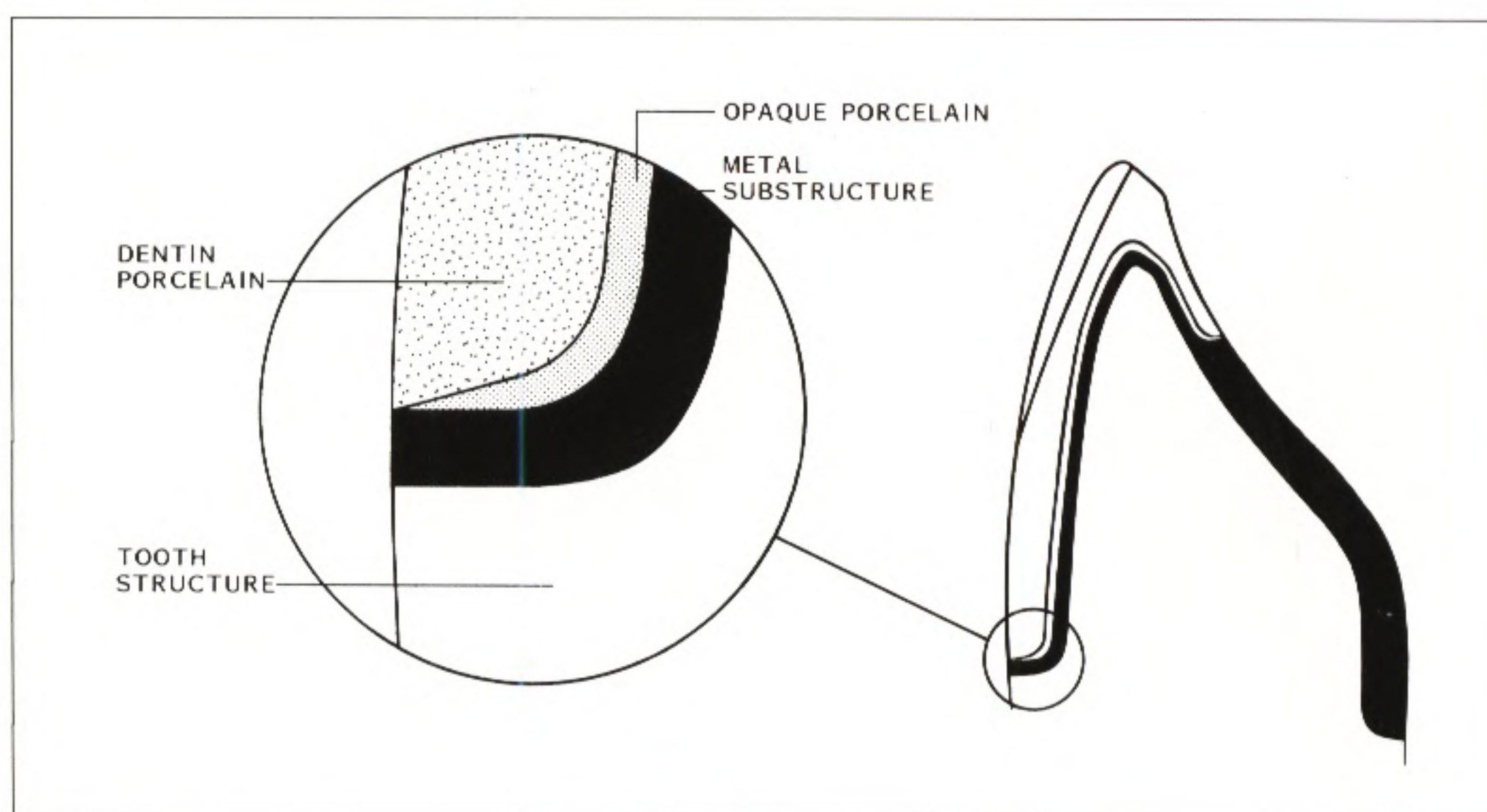


Fig 4-52 Rounded shoulder or deep chamfer finish line.

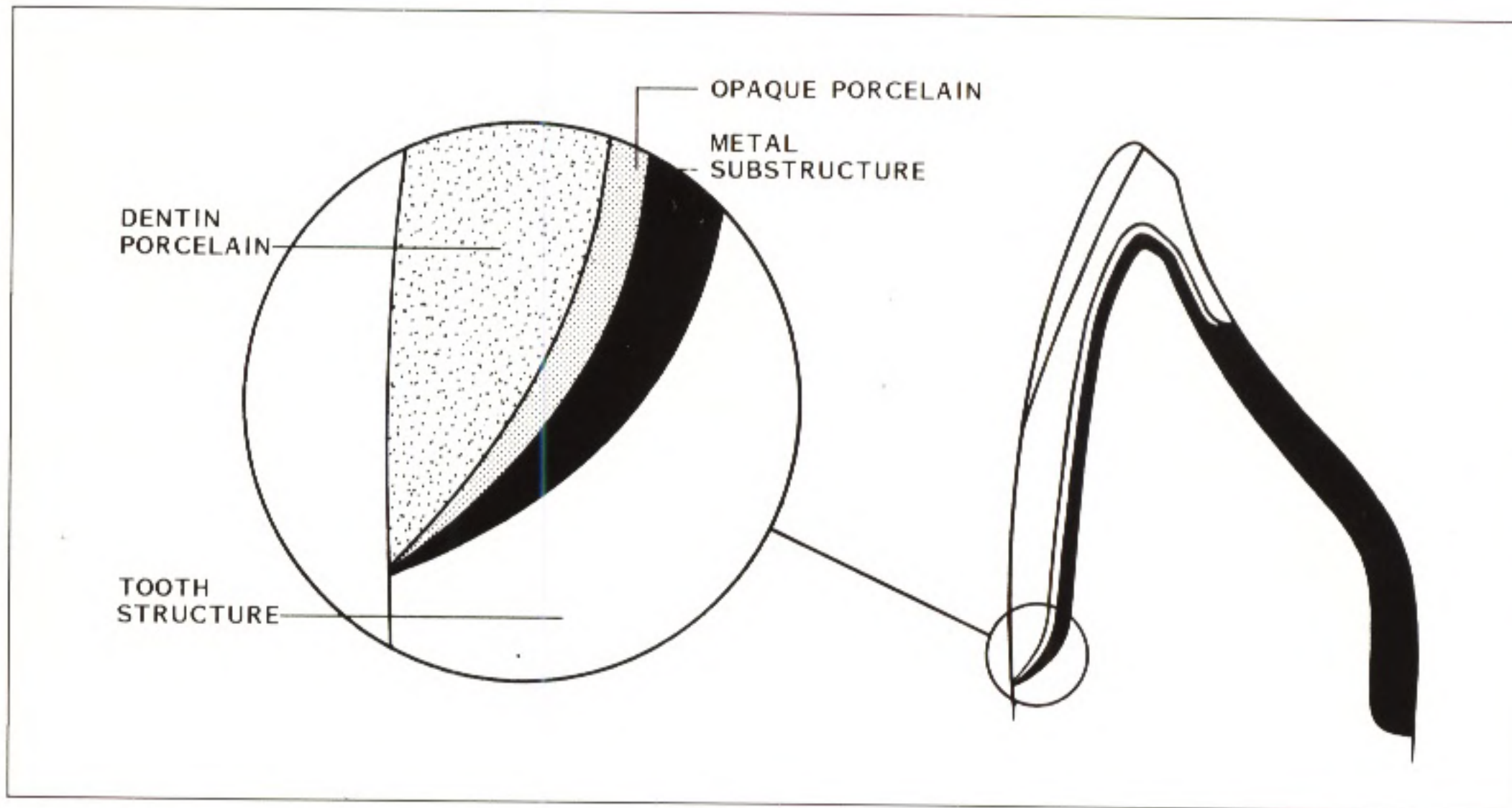


Fig 4-53 Chamfer finish line.

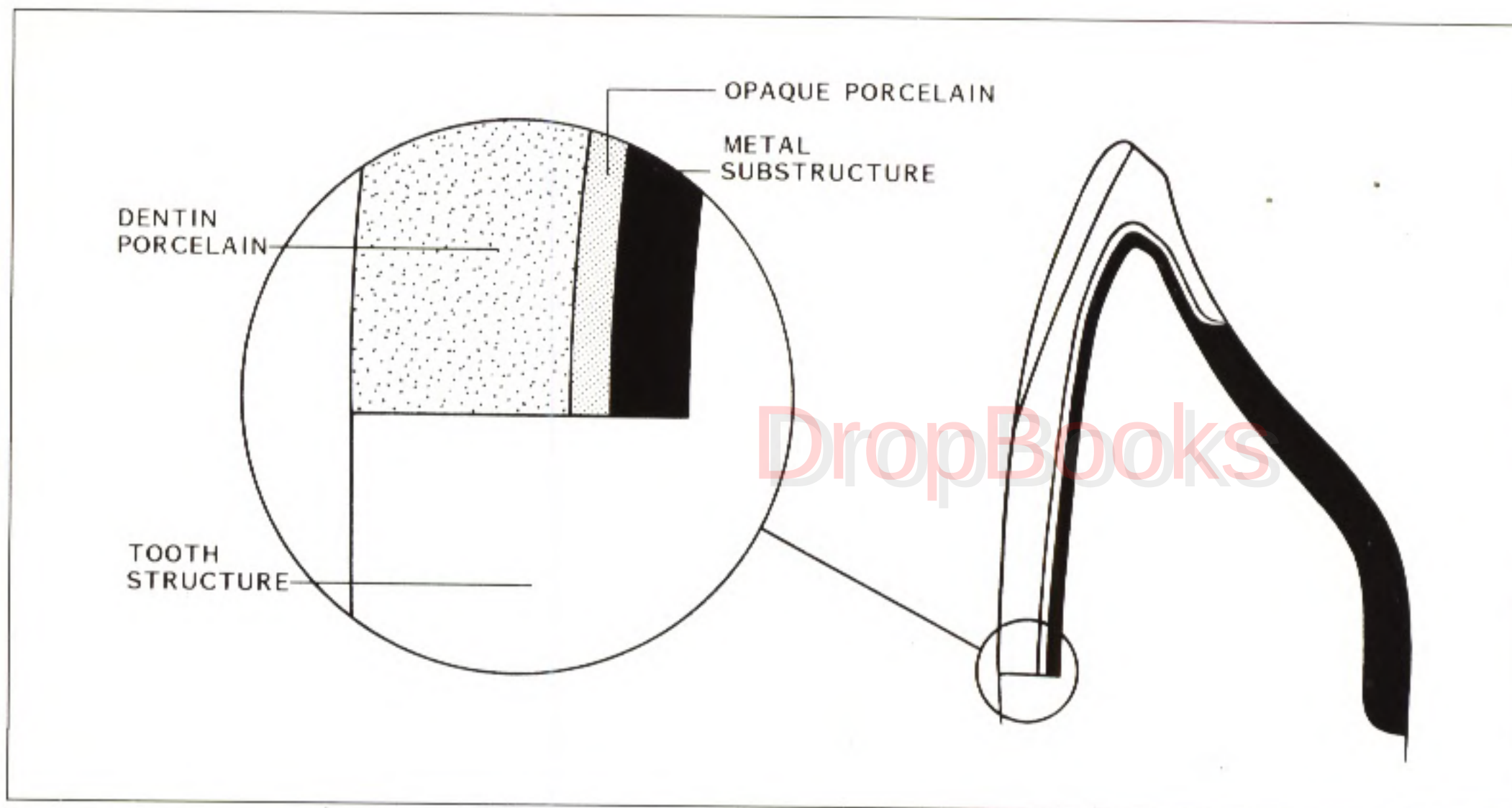


Fig 4-54 A 90-degree (or square shoulder) finish line.

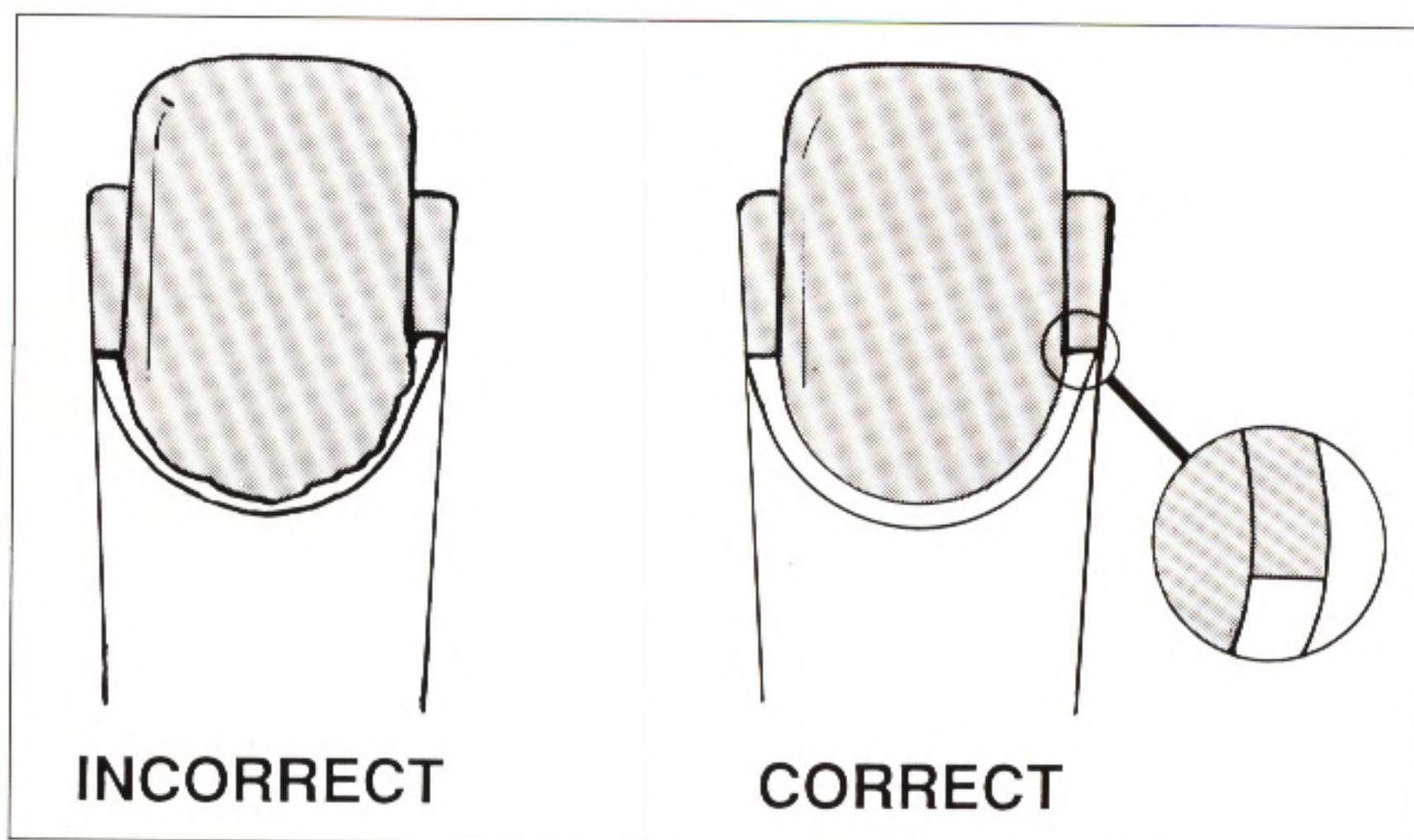


Fig 4-55 An incorrectly waxed substructure for a metal ceramic crown with a porcelain labial margin will have a narrow, irregular shoulder while a correctly designed coping will have a uniform labial shoulder that extends its full width into the interproximal areas.

(Yamamoto, 1985), but it can be managed if it is slightly rounded.

If this finish line design is to be used for a metal ceramic crown with a porcelain labial margin, there are several opinions as to where the metal should terminate in relation to the shoulder (Yamamoto, 1985). Some prefer to stop the metal axially just short of the shoulder, leaving approximately 0.5 mm of the axial wall exposed. Others recommend extending the metal 0.5 mm or so onto the shoulder itself (Vyronis, 1982). Most often the metal is terminated at the junction of the axial wax and the shoulder.

The same substructure design principle prevails here as in all other areas; the ultimate goal is to have a uniform thickness of porcelain for the porcelain labial margin (Fig 4-55). If the shoulder is wider than ideal because of previous restorations, erosion, dental caries, or some other factor, that extra width should be replaced by the metal substructure rather than the porcelain margin.

A porcelain margin 0.7 to 1 mm wide is considered ideal because it allows 0.2 mm for opaque porcelain and 0.5 to 0.8 mm for margin porcelain. Avoid porcelain thicknesses greater than 1 mm with porcelain labial margin restorations; when the shoulder width exceeds 1 mm, the porcelain margin becomes more difficult to fabricate, and this may result in a slightly weaker porcelain margin.

Summary

It should now be apparent that the essentials of metal ceramic substructure design are similar for a variety of restorations, from single-unit anterior and posterior crowns to anterior and posterior fixed partial dentures. Aside from a few minor modifications, the substrate for a porcelain labial margin restoration is prepared in essentially the same manner as any other metal ceramic substructure. Taking the time and care to plan and prepare a well-designed metal ceramic substructure will in part ensure the longevity of the final prosthesis. Having applied these principles, chapter 5 will discuss how to properly sprue, invest, and cast the finished waxed patterns.

Substructure design checklist

1. Begin the design phase with an accurate full-contoured waxup.
2. Are occlusal contacts located 1.5 to 2 mm from the porcelain-metal junction?
3. Do you have a minimum metal thickness of 0.3 mm for porcelain-bearing areas?
4. Remember, there is no maximum thickness of metal.
5. Are all surfaces to be veneered with porcelain smooth with rounded, convex contours? Have you removed all sharp line angles?
6. Does the porcelain-metal junction have a sharp, well-defined cavosurface but rounded internal line angles?
7. Has the substructure been designed to provide a porcelain veneer with a nearly uniform thickness with no areas of more than 2 mm of unsupported porcelain? (The veneer thickness may actually vary from 1 mm in the gingival third to a maximum of 1.5 to 2 mm at the incisal or occlusal surface.)

The Fundamentals of Spruing, Investing, and Casting

Introduction

Success in fabricating metal ceramic crowns and fixed partial dentures depends to a large extent on obtaining high quality castings that are properly designed and well fitting. This chapter will provide an overview of many important topics related to the fundamental principles of spruing, investing, and casting.

Spruing techniques

A spruing system is intended to create a channel or series of channels in the set investment through which molten alloy flows to reach the pattern areas. Consequently, one of the first decisions you must make when preparing a waxup for investing is what type of sprue system to use. For best results, each case should be analyzed carefully to make certain sufficient molten alloy will be made available to reproduce all of the invested units.

There is no single method of spruing that is universally accepted as the technique of choice. On the contrary, opinions among dental technicians and recommendations from alloy manufacturers differ so widely in fact, that at times they may be in direct conflict with one another. For example, one manufacturer may suggest direct spruing whereas another may insist that only indirect spruing be used with their alloys. To complicate matters, even reports in the dental literature offer conflicting views of the subject. Nonetheless, it is extremely important to understand the general principles of spruing, including the spruing method (direct versus indirect), sprue placement (or location), sprue gauge, sprue length, reservoir location, constricted spruing, sprue composition (wax versus plastic), and the value of prefabricated wax sprues.

Spruing methods

Wax patterns can be sprued in one of two different ways—directly or indirectly. Each method has its advantages and disadvantages, so you should understand the philosophy behind the two techniques, because they do differ.

Direct spruing

As the name alone indicates, with direct spruing the flow of molten metal is straight (direct) from the casting crucible to the pattern area in the ring. This method of spruing is not as involved as the indirect method and requires less time and effort. A straight sprue former is luted (attached) to the thickest part of the wax pattern at one end and secured to the crucible former at the other. The sprue former can be modified by placing a ball, or round reservoir, between the pattern and the button. Even with the ball reservoir, the spruing method is still direct. Direct spruing is used most frequently for single units and small, multiunit patterns (Fig 5-1). A basic weakness of direct spruing is the potential for suck-back porosity at the junction of restoration and the sprue (Fig 5-2).

Indirect spruing

With indirect spruing, molten alloy does not flow directly from the casting crucible into the pattern area in the heated mold (Naylor, 1986; Rousseau, 1984). Instead, the casting alloy takes a circuitous (indirect) route before it reaches the pattern areas, thus the name *indirect* spruing (Fig 5-3). With this method of spruing, the connector (or runner) bar is often 6- or 8-gauge round wax to which the wax pattern sprue formers are attached on one side with two larger ingot sprue formers on the other side, as shown in Fig 5-3. The bar's large volume houses molten metal so the pattern areas fill with metal first and are able to draw



Fig 5-1 A casting produced using direct spruing. The straight sprue former can be modified with a ball reservoir, but the spruing method is still direct.

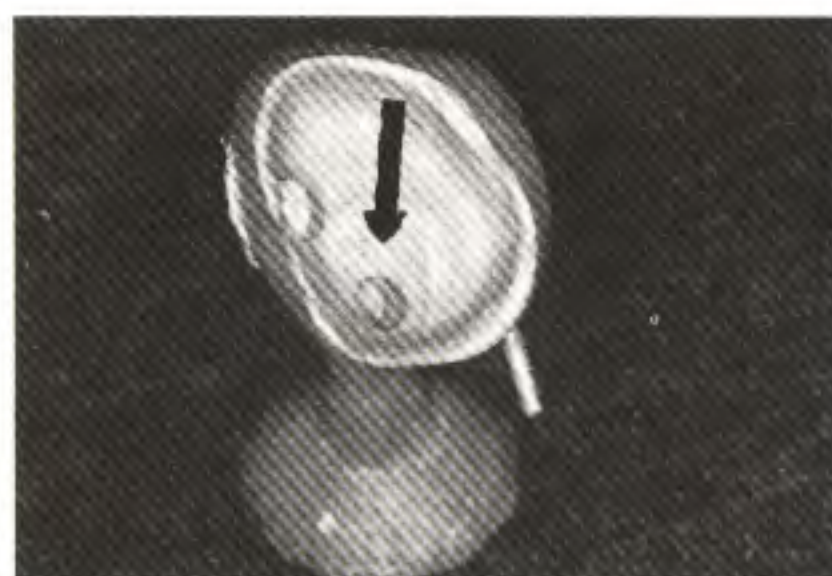


Fig 5-2 One problem with direct spruing is the increased likelihood of suck-back porosity at the restoration-sprue junction. Suck-back porosity may not be detected externally but may be obvious on examination of the internal aspect (arrow) of the casting.

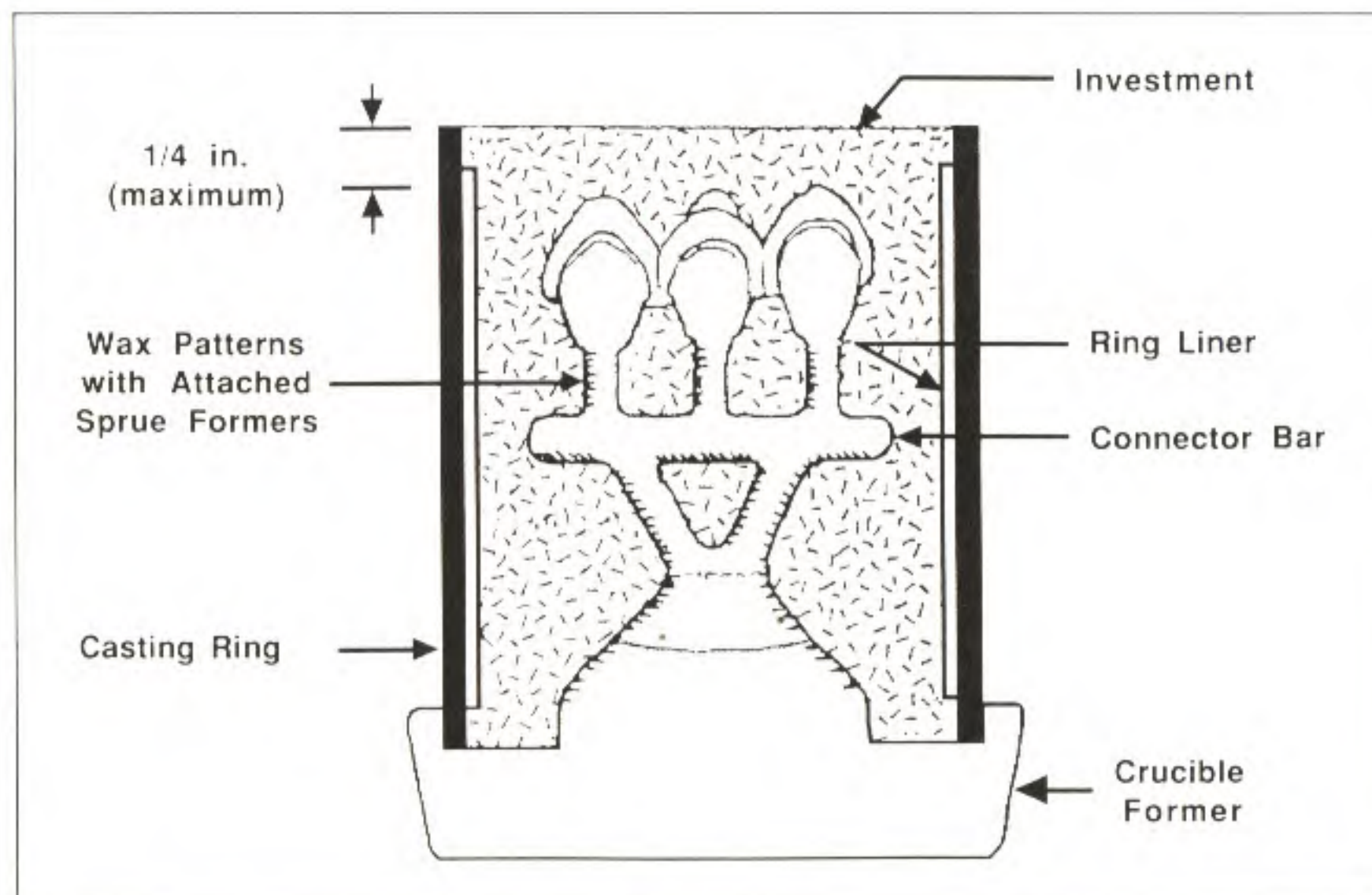


Fig 5-3 These general guidelines for indirect spruing should be adjusted to meet the requirements of each case.

upon the reservoir if additional alloy is needed to complete the solidification process (Dootz and Asgar, 1986). Consequently, the connector bar is often referred to as a "reservoir" bar. In addition, the composition of an alloy will influence the manner in which it fills the mold. For example, a palladium-silver alloy fills unidirectionally, whereas Type III gold fills in a random (scattered) fashion (Dootz and Asgar, 1986).

Opinions differ as to the value of indirect spruing for a single crown or multiple single units (Young et al, 1987). Although direct spruing can produce acceptable results, in many instances indirect spruing offers advantages such as greater predictability and reliability in casting plus enhanced control of solidification shrinkage, to mention only a few. Prefabricated indirect sprue formers, for example, permit standardizing a technique for greater consistency. The prefabricated sprue formers also help to eliminate errors in sprue design and reservoir location compared to direct spruing. Additionally, after a casting is made, the

indirect sprues can be sectioned and reused (Fig 5-4) far more readily than accumulated buttons.

Sprue former placement

Ideally, the sprue former attached to the waxup (pattern sprue former) should be luted to the thickest part of the pattern to allow the molten alloy to flow from regions of large volume (thick areas) to regions of lesser volume (thin sections). Placing the sprue former elsewhere might result in an incomplete casting if a thin section undergoes solidification before the mold can fill completely. Of course, there are exceptions to every rule. With thin anterior copings this option is not available or advisable. The most practical sprue location is the midincisal area. The same logic should be used to locate an appropriate site on a molar coping that is to receive full porcelain coverage.

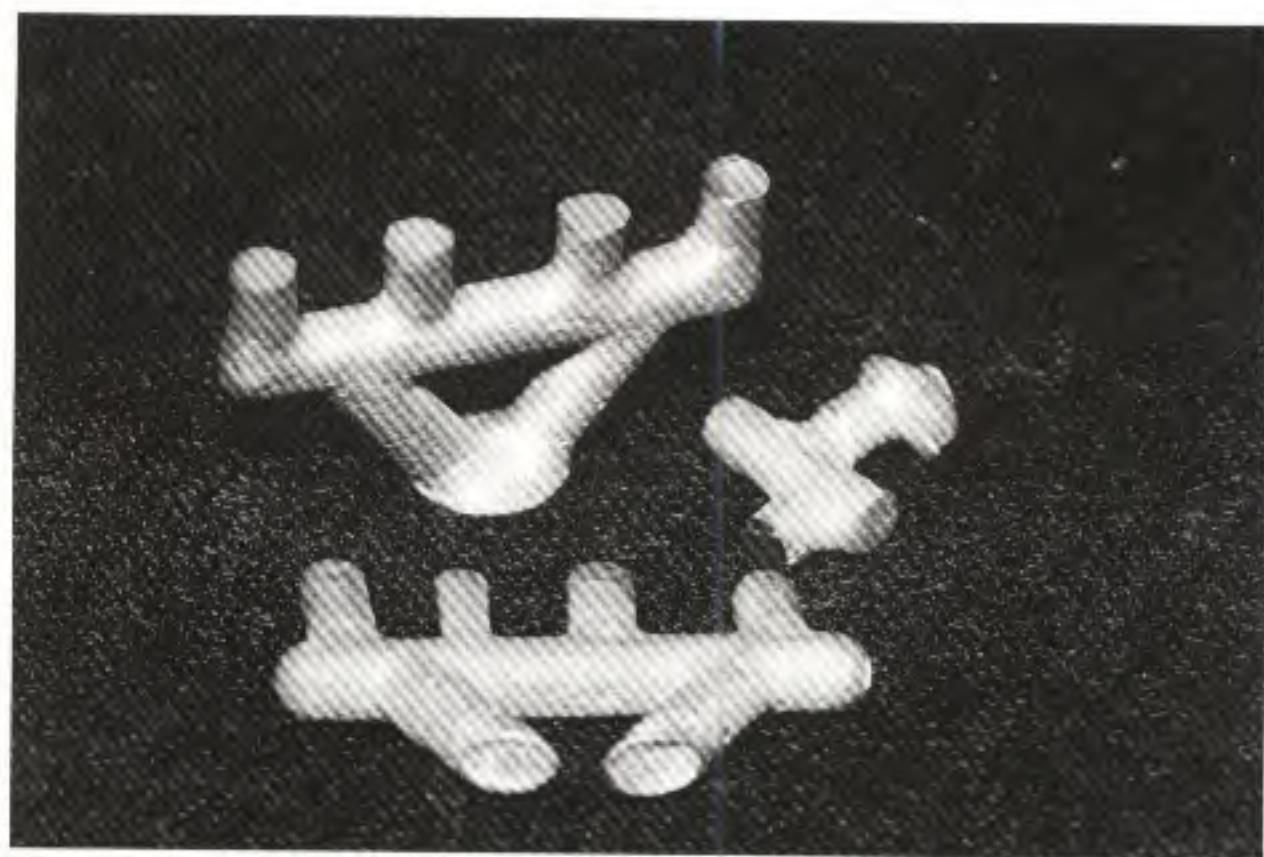


Fig 5-4 The cast indirect spruing network can be sectioned and reused more readily than buttons of spent metal. On the other hand, accumulated buttons cannot be cut up and recycled because of their large size.

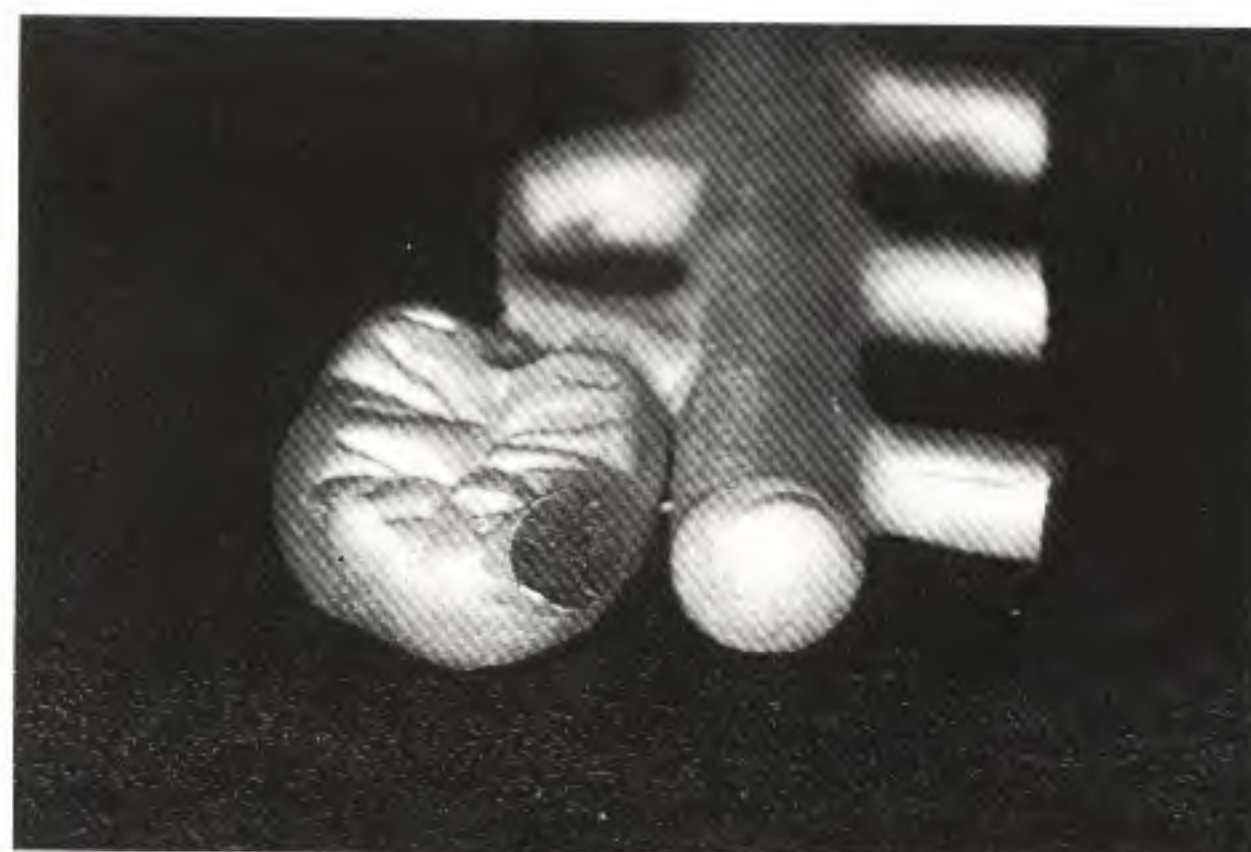


Fig 5-5 Using a Type III gold casting as an illustration, this large Williams Tri-Wax connector bar would be better able to support large metal ceramic pontics and retainers than a smaller-diameter prefabricated wax pattern. Note that the wax pattern was located off the reservoir bar approximately 5 mm.

Sprue former gauge

A pattern sprue former of sufficient size should be selected to supply the volume of alloy required of the patterns to be cast. The round wax sprue formers are conveniently identified with a gauge number (ie, 10, 8, 6). The larger the number, the smaller the sprue former's diameter. Alloy manufacturers invariably include size recommendations with their alloys, but these suggestions are made without actually seeing specific wax patterns. Therefore, it is the technician's responsibility to carefully examine the wax patterns, evaluate the particular requirements of each case, and select the appropriate gauge. With indirect spruing, the reservoir should be equal to or larger than the thickest cross-sectional area of the largest pattern. This requirement is especially critical when metal pontics and large molar retainers are sprued (Fig 5-5).

Sprue former length

With the direct spruing method, the sprue former should be long enough to position the wax patterns outside the heat center of the ring and into a cold zone (Naylor, 1986; McLean, 1980; von Weber, 1977). The actual length of the sprue former will vary with the type and size of the crucible former and the casting ring used.

With indirect spruing pattern placement off the con-

necter bar is recommended to ensure location of the patterns outside the thermal zone, or heat center, of the investment. Experience has shown that a 5-mm-long pattern sprue former is often sufficient to meet this requirement (Fig 5-5). Incomplete castings may occur if the wax patterns are positioned too far from the connector bar, because alloy may solidify in the sprue channel before the pattern has filled completely.

Orientation of the wax pattern

The casting of an otherwise properly sprued pattern can be jeopardized if the pattern is not correctly oriented in the casting ring. Attach the sprue former to the thickest portion of the wax pattern. Do not create sharp 90-degree angles between the sprue former and the wax pattern or position the pattern so the alloy would have to flow back toward the ring entrance. It is essential to take advantage of centrifugal and gravitational forces by positioning the wax pattern such that the alloy is cast toward thinner sections, such as the margins. This is accomplished by positioning the margins of the patterns to the trailing edge in the casting ring. Before investing the patterns, place a wax dot on the crucible former (Fig 5-6a) to provide an orientation reference after the patterns have been invested (Fig 5-6b).



Figs 5-6a and b A wax orientation dot on the crucible former (*left*) will be picked up by the investment (*right*) and help you to locate the trailing edge of the wax patterns for casting.

Location of the reservoir

The reservoir portion of a spruing system, be it a 6-, 3-, or 1-gauge bar or round ball, should be positioned in the *heat center* of the ring (Alleluia, 1980; Ingersoll and Wandling, 1986; McLean, 1980; Naylor, 1986). This permits the reservoir to remain molten longer and enables it to furnish alloy to the patterns until they complete the solidification process (Figs 5-7 to 5-10).

Aside from being in the heat center, the reservoir should have the largest mass of any part of the sprue system. In other words, you do not want to cast a button if you can avoid it. One of the best ways to ensure no button is cast is to weigh the wax patterns and supporting sprue system. This is done simply by weighing the crucible former first and then weighing the completed waxup after spruing is complete (Figs 5-11 and 5-12). The difference between the two measurements is the weight of wax above the top of the crucible former (ie, the sprue system). That difference is all that is necessary to cast. The wax pattern-alloy conversion chart (see Appendix C) can provide an estimate of the amount of alloy required. Do not overestimate the alloy weight, because no button is desired with indirect spruing. A button, or wax patterns larger than the reservoir, competes with the connector bar as the largest mass of metal (Civjan et al, 1972) and influences the location of the heat center in the casting ring (Figs 5-13 to 5-15) (Naylor, 1986).

With direct spruing where no reservoir ball is used, a button is needed, because it then serves as the source of molten metal for the pattern during solidification.

Constricted spruing

Tapering the sprue former at its attachment to the wax pattern rather than flaring this area is referred to as "constricted spruing" (von Weber, 1977). The taper is thought to permit the sprue former to function like a true reservoir, thereby decreasing the likelihood of suck-back porosity (McLean, 1980; Naylor and Young, 1985; Rousseau, 1984). In practical terms, the constriction may be helpful in the mold-filling process for lower density base metal alloys. But, as the density of the metal increases, it is more apt to interfere with mold filling and lead to increased porosity (Compagni et al, 1984; Nielsen and Ollerman, 1976; Verrett and Duke, 1989; Wight et al, 1980), as explained later in the "Laws of Casting" (Ingersoll and Wandling, 1986; Naylor, 1986).

Therefore, it is recommended that you follow this general rule: the greater the alloy density, the greater the sprue-pattern access. Keep in mind that some individuals will report success with constricted spruing for many alloy systems, regardless of density levels. This is not to say that both techniques will not work. However, the recommendation for the limited use of constricted spruing is to promote a technique more likely to offer consistent and highly reproducible results.

Sprue former composition: wax versus plastic

It is not often emphasized, but the burnout techniques should be different for wax and plastic sprue formers.

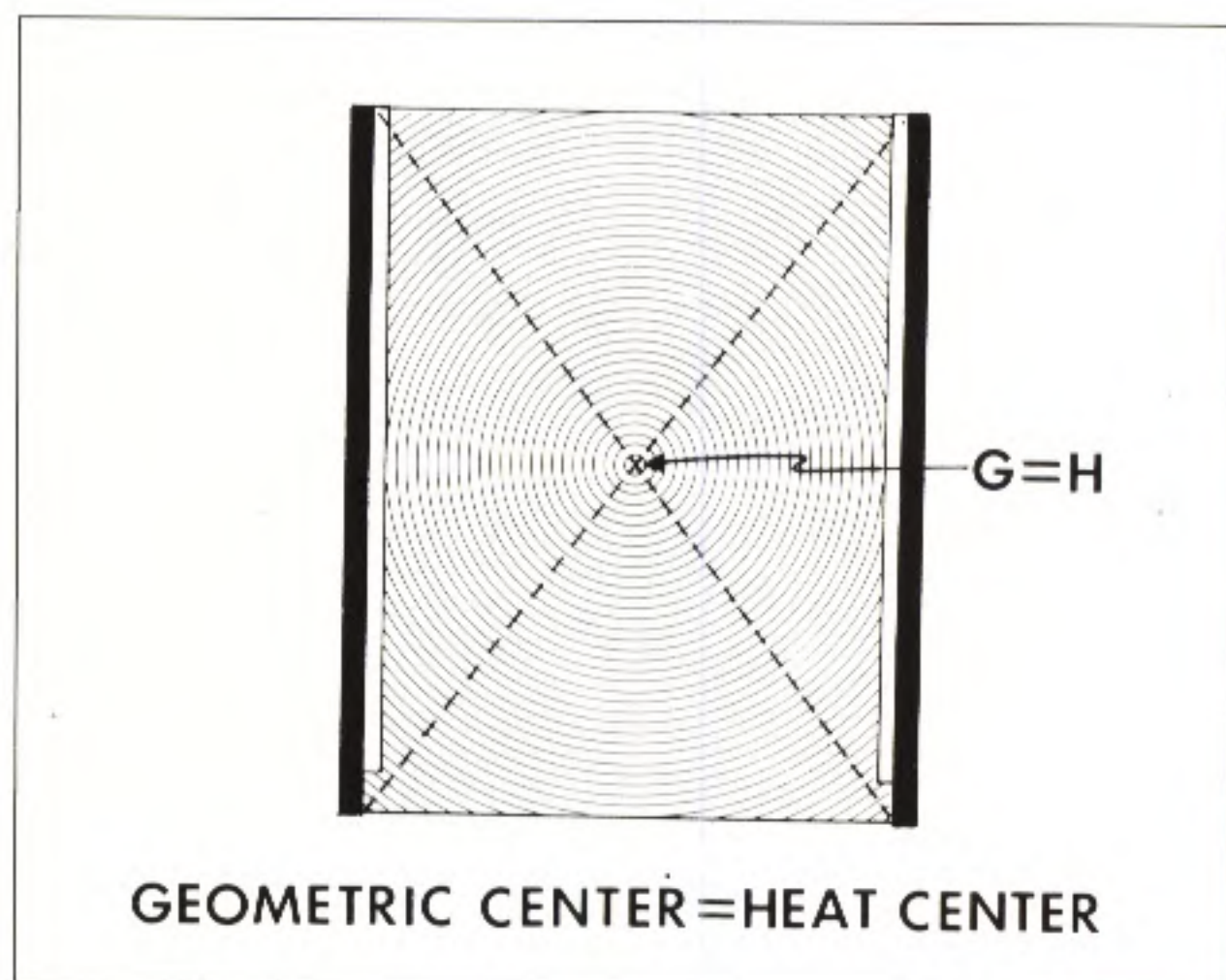


Fig 5-7 It may be incorrect to conclude that the geometric center and the heat center are one and the same.

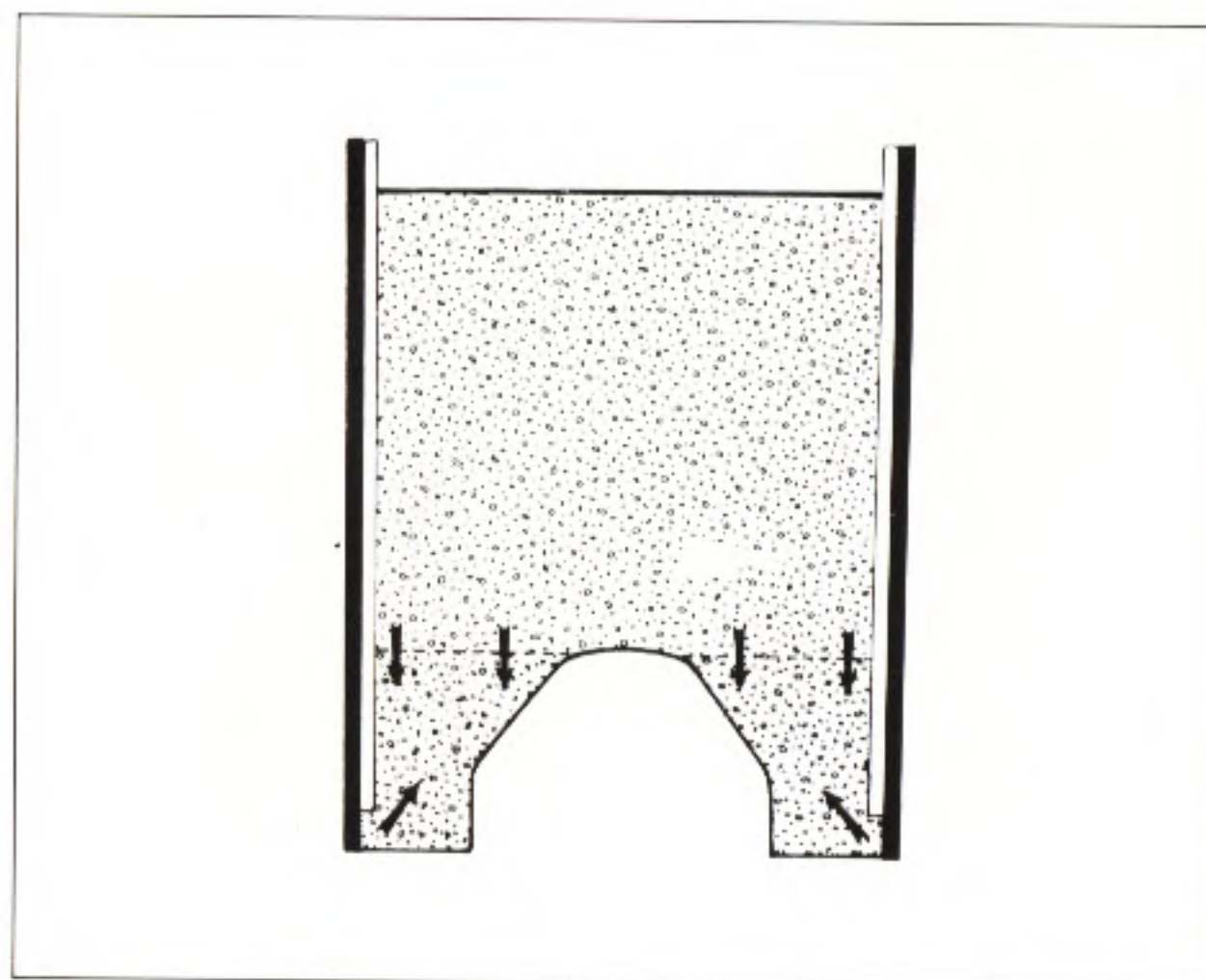
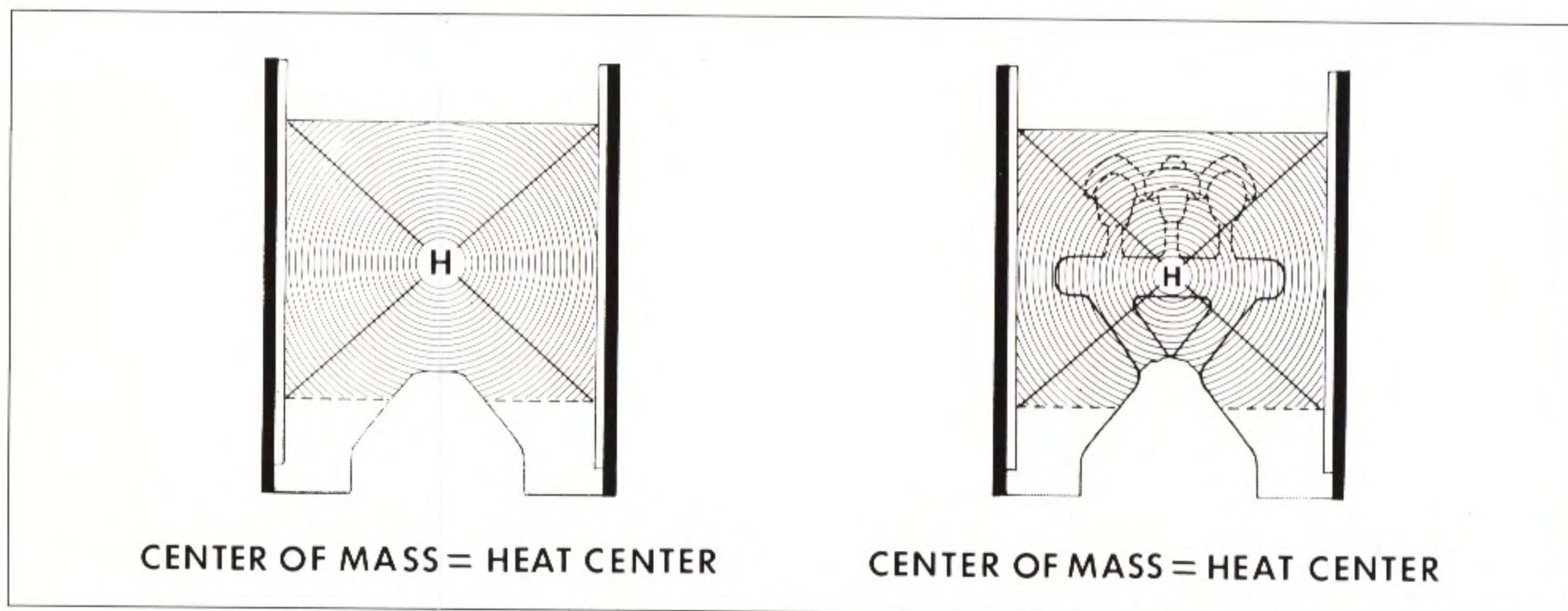
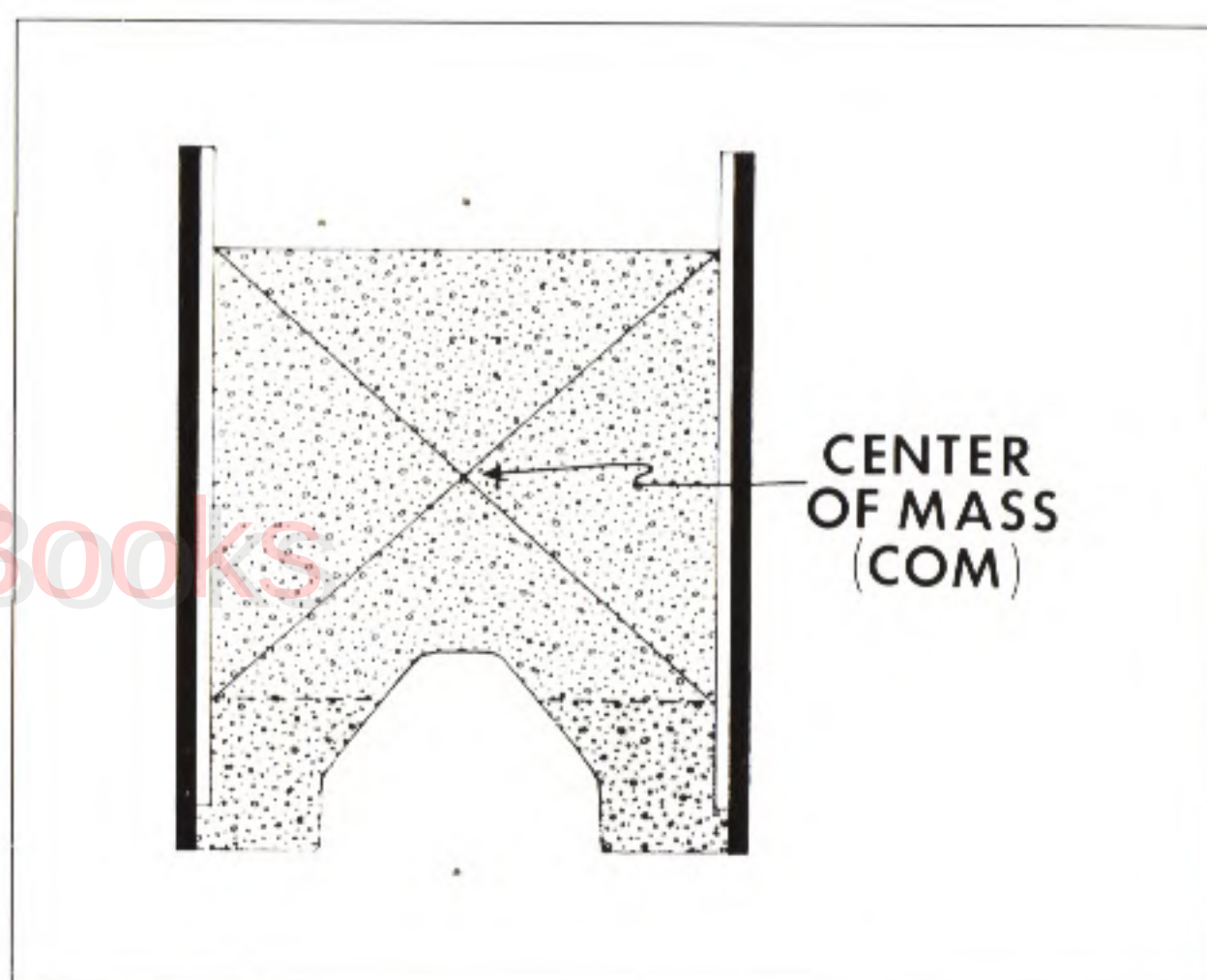


Fig 5-8 The investment surrounding the crucible former is less likely to contribute significantly to the heat center of the ring.

DropBooks

Fig 5-9 An area other than the geometric center of the ring may be the location of the ring's true thermal zone or heat center. I have termed that area the "center of mass" (COM) of the investment.



Figs 5-10a and b The center of mass can also be the heat center of the ring (*left*) when it contains the largest mass of molten alloy (*right*).



Fig 5-11 The opening in the crucible former is filled with wax and the orientation dot is placed. The crucible former is placed on a scale and weighed. The weight of the crucible former can be permanently recorded on the base with an indelible pen.



Fig 5-12 A prefabricated wax sprue former, with attached wax patterns, is placed in the crucible former, and the entire assembly is weighed.

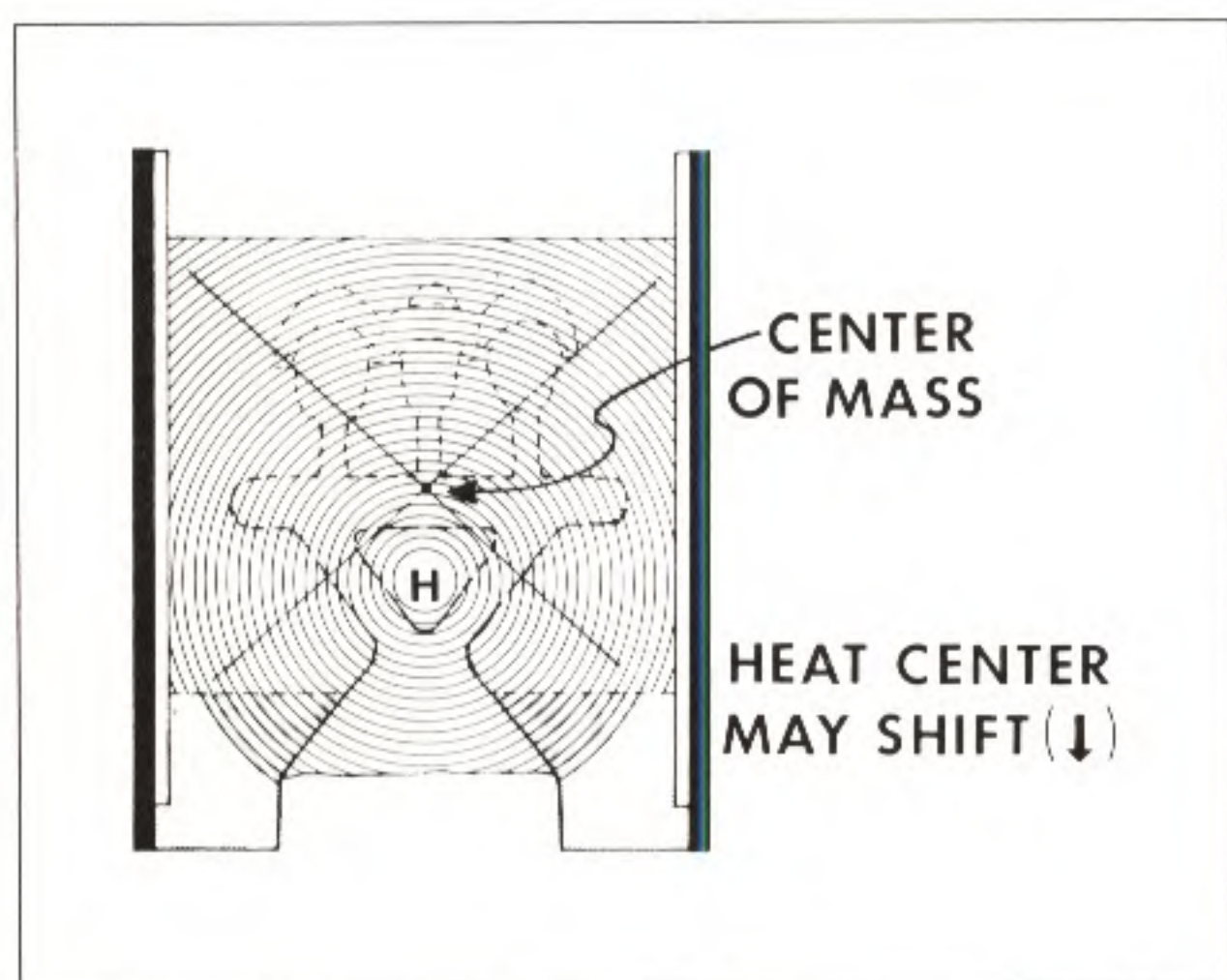


Fig 5-13 A large button can compete with the connector bar to be the "reservoir" and cause the heat center to shift from the bar toward the button.

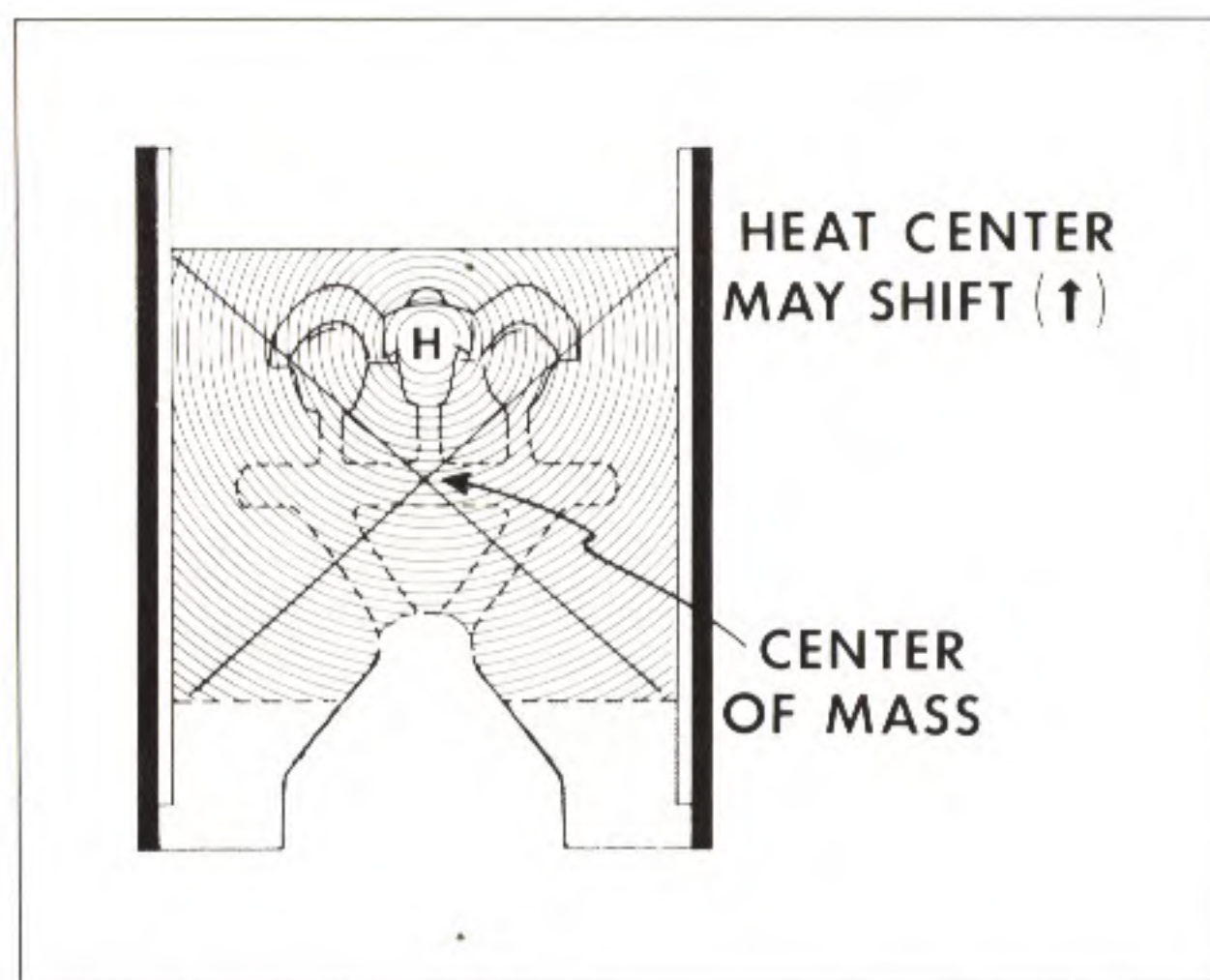
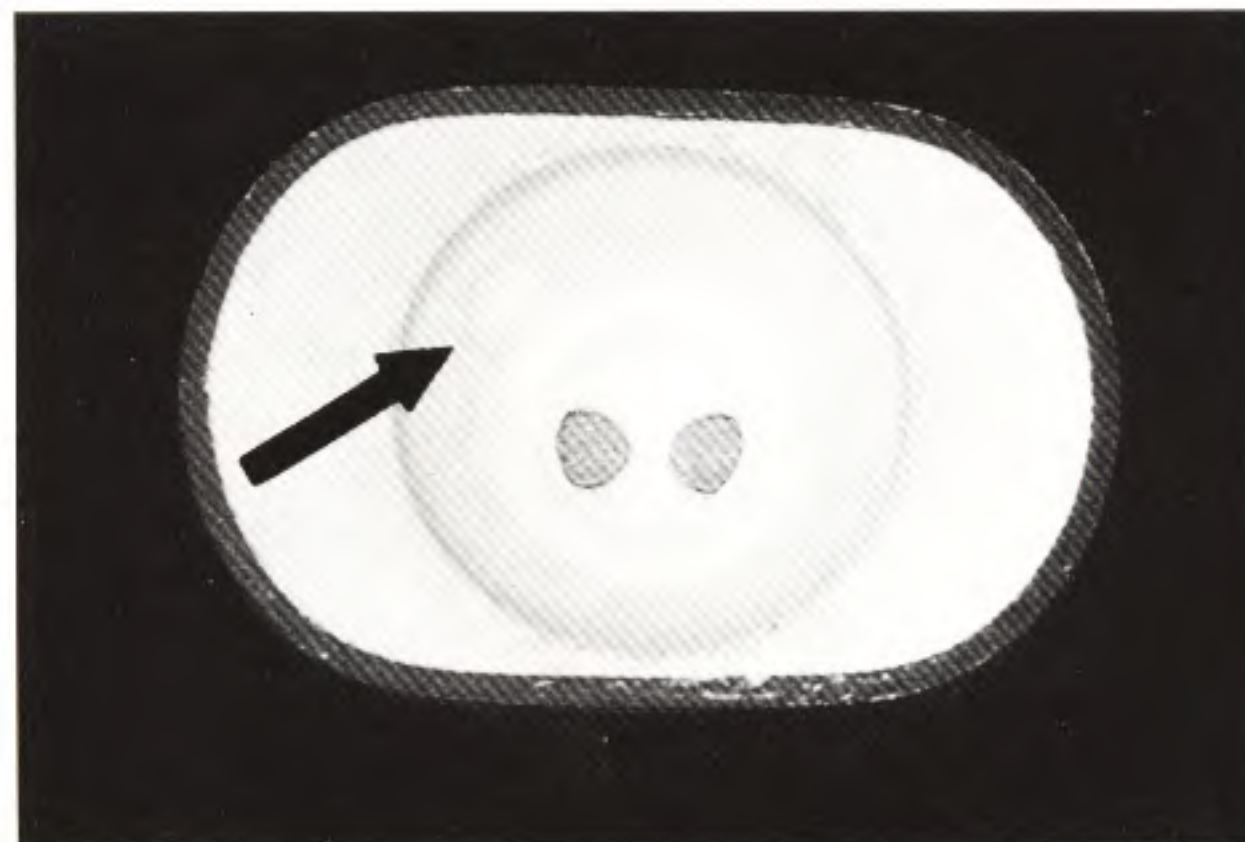
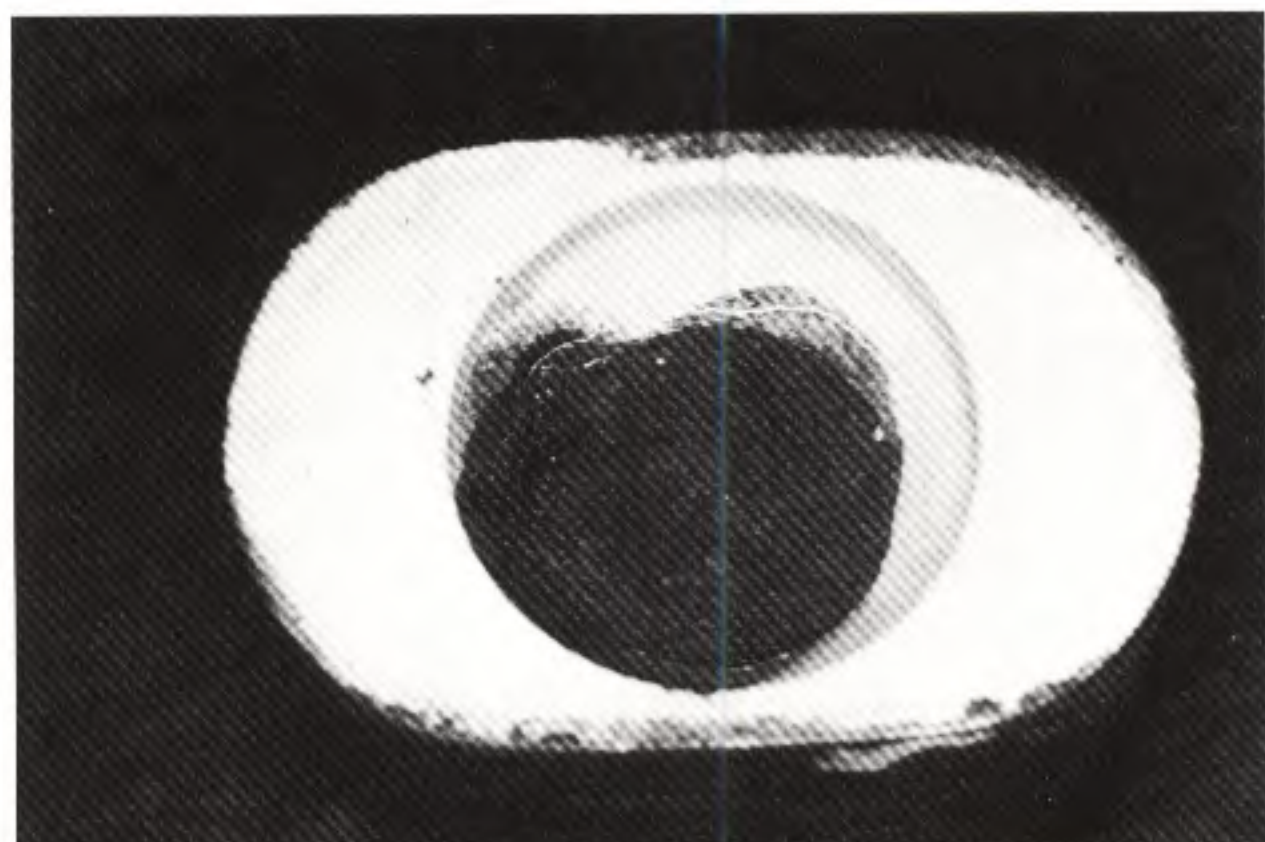


Fig 5-14 Likewise, the heat center can shift upward toward large patterns when no button is cast and the restorations weigh more than the connector bar.



Figs 5-15a and b As one is able to better estimate the amount of alloy needed, the button (*left*) will get smaller and smaller until it is completely eliminated (*right*). Note the presence of the small concavity (*arrow*) formed in the investment by the wax orientation dot.



Fig 5-16 Examples of prefabricated wax patterns include the Belle de St Claire Ready Sprues (*left*) and direct and indirect wax sprues from the Williams Tri-Wax system.

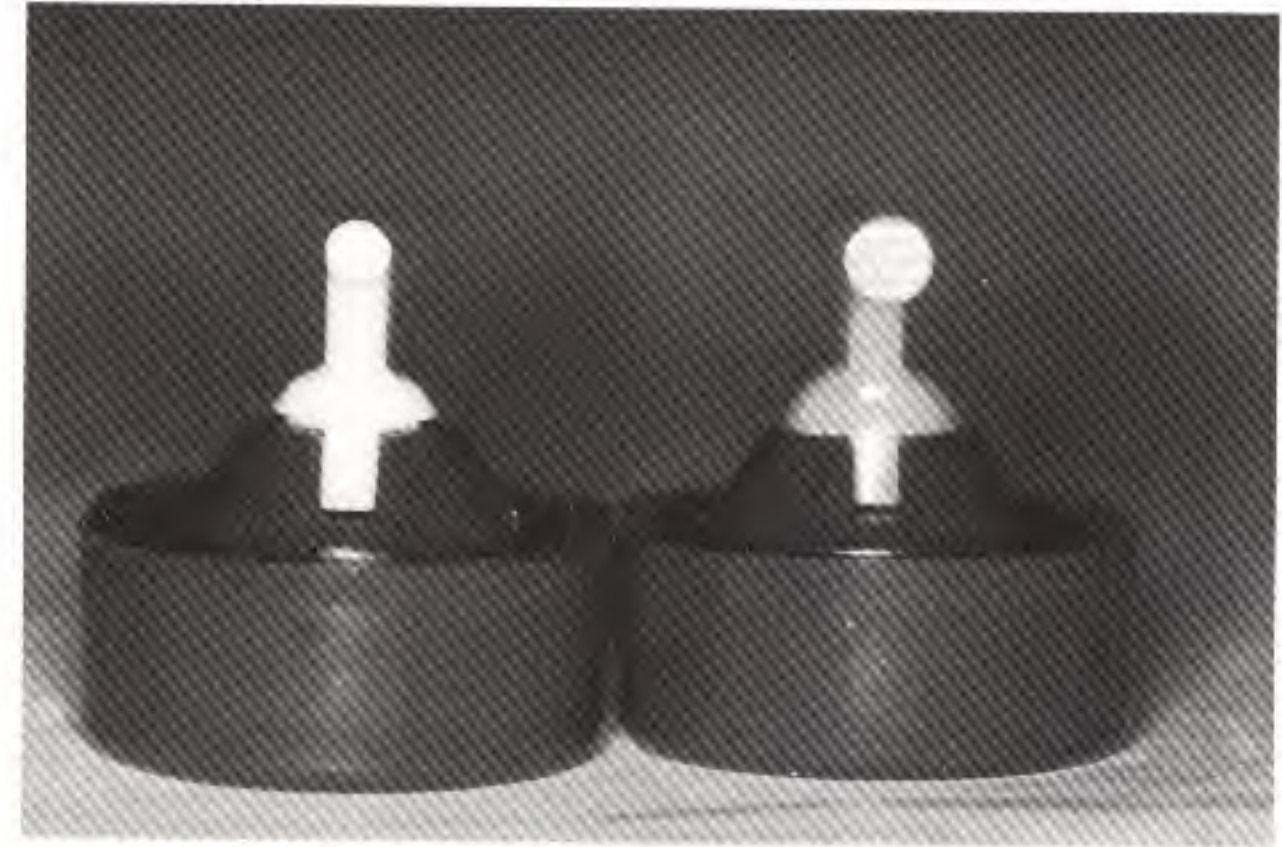


Fig 5-17 The cross-sectional area of the Williams Tri-Wax bar (*right*) is much larger than that of the Belle de St Claire Ready-Sprue (*left*). The bar of the Tri-Wax indirect sprue has approximately the same vertical position in the ring as a Ready Sprue.

Casting wax melts readily in the normal course of the wax elimination (burnout) process, leaving little concern for carbon residues after heat-soaking at the recommended maximum temperature. In fact, casting waxes that are certified by the American Dental Association will not leave a residue of more than 0.1% of the specimen's original weight. There is no assurance however, that all wax sprue formers perform equally well. Furthermore, plastic sprue formers do not burn out completely through the lower temperature range; with plastic there is a greater potential for carbon residue to remain in the mold. Plastic undergoes more expansion before softening than does wax, a characteristic that may be responsible for investment cracking. More importantly, if the pathway for the escape of molten wax is blocked by unmelted plastic, the wax may overheat (boil), and erode the inner surface of the mold. As a result, the castings may have a higher degree of surface roughness.

To overcome this problem, manufacturers of plastic sprue formers recommend applying a layer of wax over the entire surface of the plastic sprue former to produce an escape mechanism for the melting wax patterns. This procedure not only requires more time but can increase the amount of irregularities in the investment if the wax is not flowed evenly and smoothly over the plastic components. Therefore, a two-stage burnout is recommended for plastic sprue formers (Alleluia, 1980) with a 30-minute heat soaking at 800°F for the first stage, as recommended by Tombasco and Reilly (1987). When the oven reaches this temperature, burnout for 30 minutes (single ring), then reset the oven to the desired high temperature and continue wax elimination (burnout).

Prefabricated sprue formers

Spruing and investing can be made easier, and certainly more consistent, by using prefabricated wax sprue formers (Naylor, 1986). In particular, prefabricated indirect sprues have different-gauge connector bars to meet the needs of individual cases. When used properly, ready-made wax patterns offer a greater opportunity to obtain a predictable and time-saving method of spruing. More importantly, you avoid having to construct a personal interpretation of an appropriate indirect sprue design. Examples of prefabricated wax sprue formers include Ready Sprues (Belle de St Claire) as part of the Casting Oval System and the Tri-Wax Sprues (Williams Dental Company) (Fig 5-16).

Ready Sprues

The design of the Belle de St Claire Ready Sprues as prefabricated indirect sprue formers permits rapid placement of the pattern in the accompanying sprue former and consistent location of the reservoir bar in the oval casting ring. Removal of the solid center web helps to isolate the runner bar, as recommended in indirect spruing, although the Belle de St Claire Company would prefer that the web be left intact (Fig 5-16). The bar is 6-gauge for both the large and the small wax Ready Sprue patterns. This size is most appropriate for small- and medium-size wax patterns (anterior copings and small posterior metal ceramic substructures).

Make certain the oval crucible former is indexed with a drop of wax so the orientation of the wax pattern's trailing edge is known (see Fig 5-6).

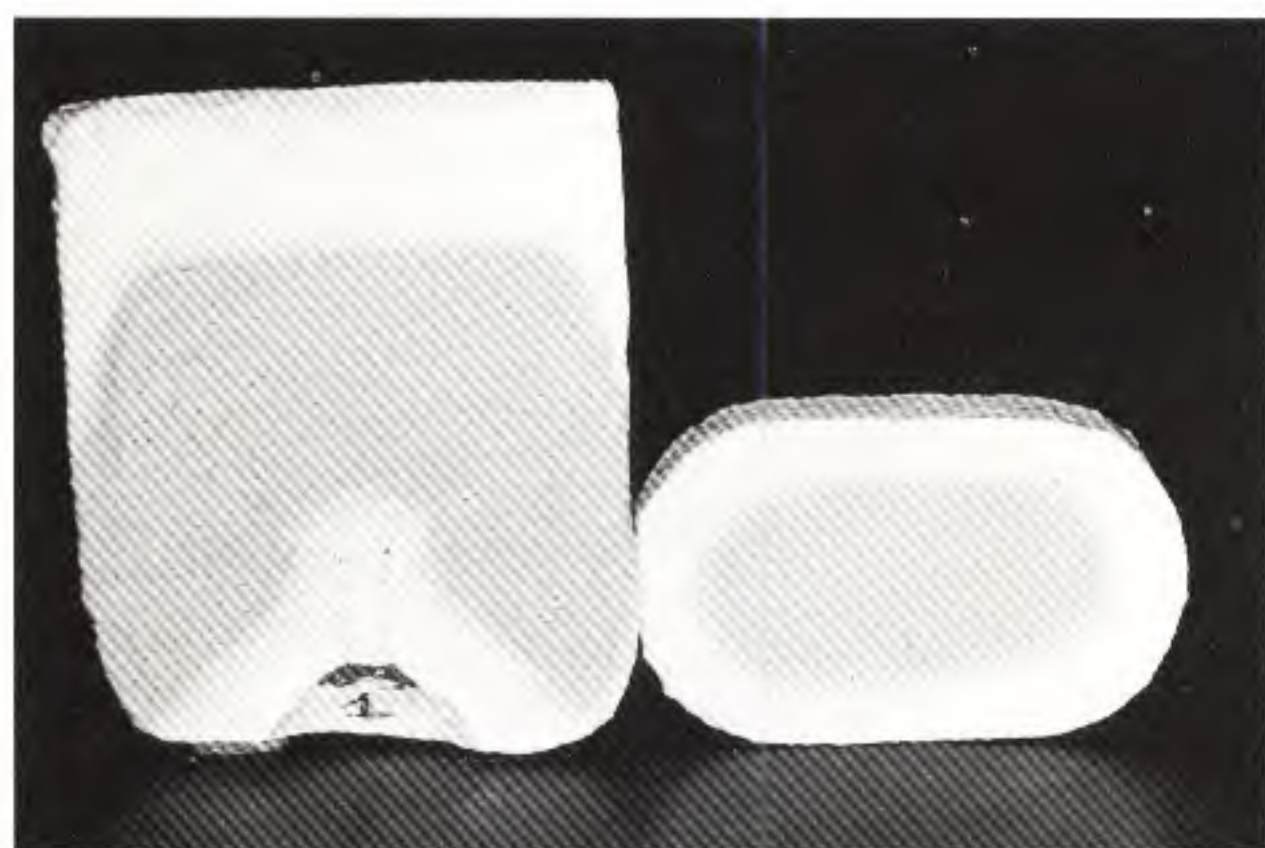


Fig 5-18 Carbon is still present in the pattern area in this carbon-containing investment even after burnout at 1,500°F for 90 minutes. The resulting reducing atmosphere is helpful to gold-based alloys (reduces oxidation), but the carbon is a potential contaminant for palladium-, nickel-, and cobalt-based metal ceramic alloys.

Tri-Wax system

The prefabricated Tri-Wax sprues from the Williams Dental Company are available as direct and indirect sprues. The direct sprues are sold in three sizes: large, small, and mini, with an 8-gauge, 10-gauge, and a 12-gauge ball, respectively. The indirect sprues have either a 4-gauge (large) or 6-gauge (small) runner bar. The large indirect sprues are particularly useful for large pontics or thick molar wax patterns (see Fig 5-5). The cross-sectional area of a Tri-Wax reservoir bar is much larger than that of a Ready Sprue (Fig 5-17).

Although the Tri-Wax pattern will seat in the small Belle de St Claire oval sprue former, the runner bar must be cut at both ends to accommodate the ring liner and provide an adequate amount of investment between the wax patterns and the casting ring. Despite the gauge differences, the height of the Tri-Wax reservoir bar in the oval ring is approximately the same as that of a Ready Sprue. Consequently, both prefabricated wax patterns can be used with the Belle de St Claire oval casting rings (Fig 5-17).

High-heat casting investments

The high melting ranges of metal ceramic alloys exceed the upper limits of the gypsum-bonded investments and require the use of either phosphate-bonded or silica-bonded casting investments. The two phosphate varieties—carbon containing and

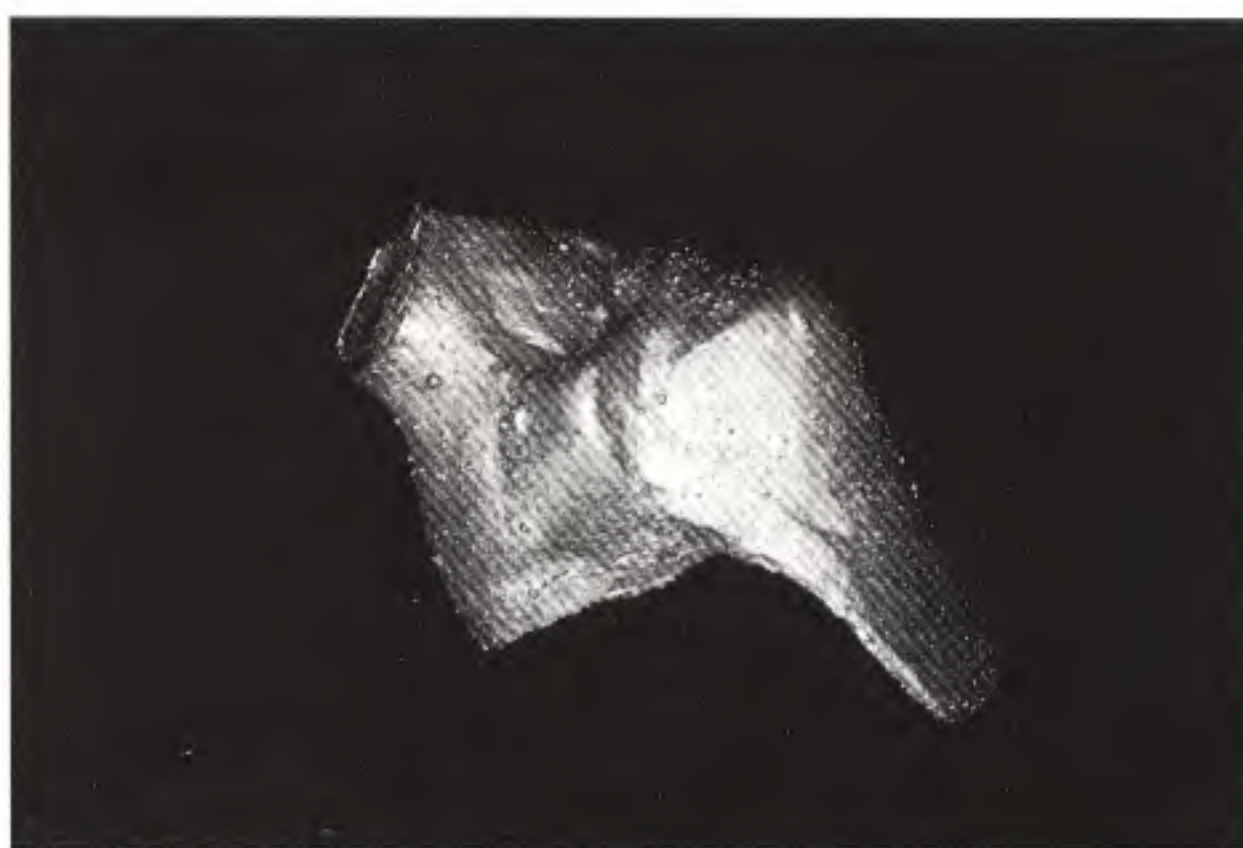


Fig 5-19 A rough casting with multiple nodules may be caused by a less-than-ideal alloy-investment pairing. Try another investment before blaming the alloy for this problem.

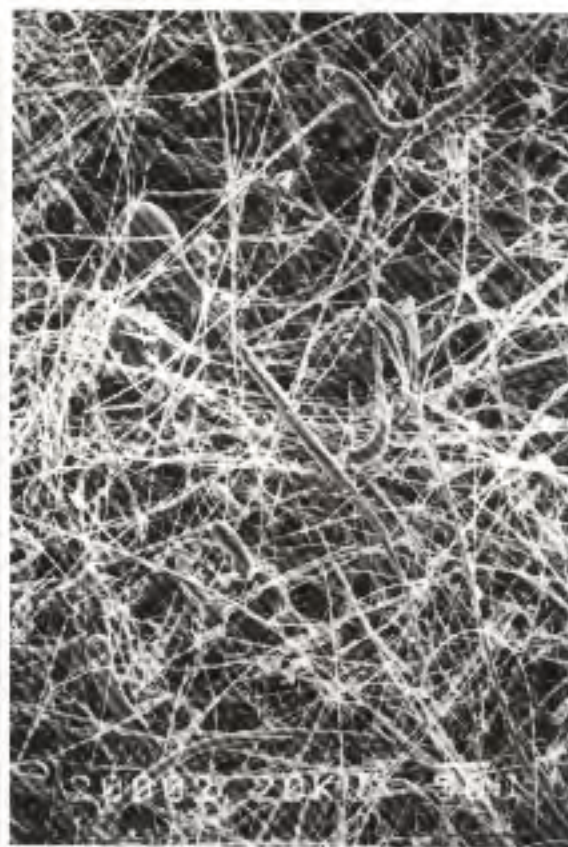
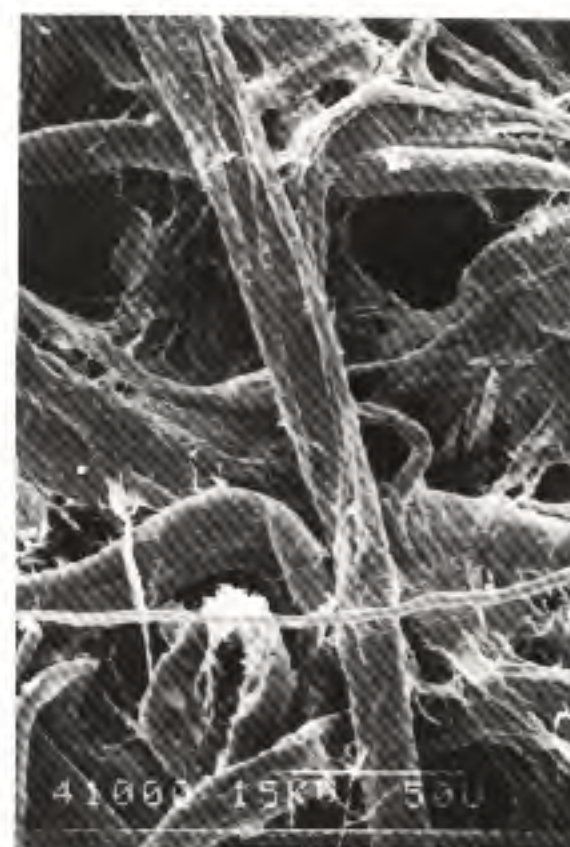
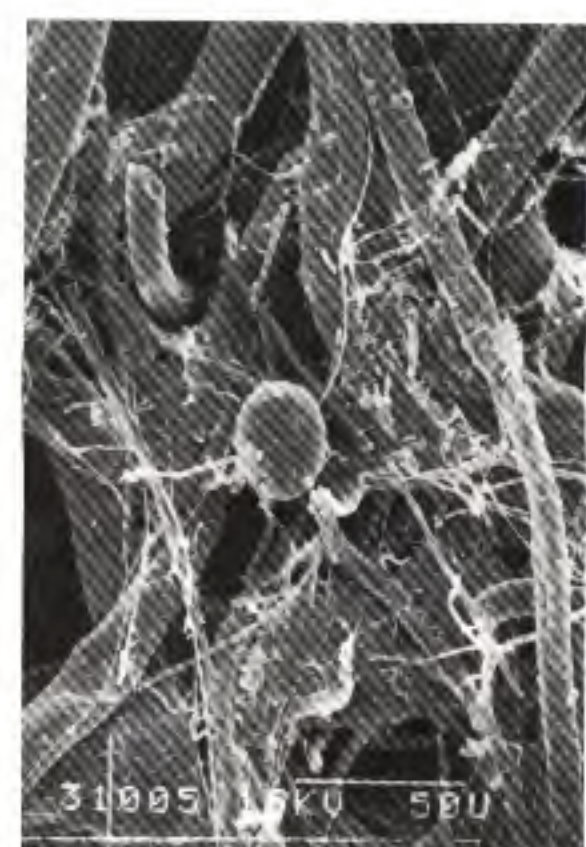
noncarbon containing—are more widely used than the silica-bonded materials.

Carbon-containing phosphate-bonded investments

A variety of carbon-containing phosphate-bonded casting investments are available. These high-heat investments are gray-black because of the presence of carbon even after burnout (Fig 5-18). Divestment of the casting is supposedly made easier if carbon is added to an investment. When mixed, this material may appear coarse in comparison to a gypsum-bonded refractory investment. Many phosphate-bonded investments require a special liquid (colloidal silica), instead of distilled water. Used full strength, this liquid provides maximum investment expansion. However, investment expansion usually will need to be adjusted to the requirements of each type of casting alloy. Variations in expansion are achieved principally by diluting the special liquid with distilled water. Carbon-containing phosphate-bonded investments are generally recommended for gold-based metal ceramic alloys.

Noncarbon-containing phosphate-bonded investments

The noncarbon investments are easily identified by their white color, before and after mixing. They were developed out of concerns for the potential interaction

Figs 5-20a to d Four types of casting ring liners.**Fig 5-20a** An asbestos liner (original magnification $\times 500$).**Fig 5-20b** A ceramic liner (original magnification $\times 150$).**Fig 5-20c** A cellulose liner (original magnification $\times 500$).**Fig 5-20d** A ceramic-cellulose combination liner (original magnification $\times 500$).

of carbon with the nickel- and cobalt-base casting alloys, as well as the palladium-based noble metal alloys. Apparently, these alloy systems are capable of dissolving available carbon to produce carbides and/or porosity (due to carbon inclusions). Some manufacturers of carbon-containing investments believe that with appropriate wax elimination, no carbon should remain after heat-soaking at the high temperature setting. They contend that more risk of carbon contamination lies with an improperly adjusted torch than in a carbon-containing investment. However, proponents of the noncarbon investments like the added security of using a carbonless system, especially since high temperature burnout ($1,600^{\circ}\text{F}$) is required to eliminate all the residual carbon (Naylor et al, 1990a).

The noncarbon investments generally have a grainy texture, like their carbon-containing counterparts. Exceptions include the fine-particle investments, Vestra-fine (3M/Unitek) or Cera-Fina (Whip Mix Corporation). These particular materials mix to a smooth, creamy consistency with ample working time.

Investment-casting alloy interaction

Variations can occur in the performance of alloys with different investments (Barreto et al, 1980; Hinman et al, 1985). It is possible that the problems attributed to a given metal are, in fact, caused by the investment. Excessive nodule formation and fins may occur more frequently with one brand of investment but not with

another (Fig 5-19). Manufacturers often indicate that their alloys may be used with virtually any commercially available phosphate-bonded investment. That may not always be true, and studies support the view that alloy-investment pairing can influence results (Teteruck and Mumford, 1966; Barreto et al, 1980; Hinman et al, 1985; Naylor, 1986, 1990a). Therefore, it may be prudent to conduct laboratory tests for an adverse alloy-investment interaction before making a large purchase of a new product (Naylor, 1990).

Casting ring liners

Asbestos had been the traditional material for lining casting rings until it was learned that it posed a potential health risk to dental laboratory technicians (Davis, 1987; Palmer et al, 1961; Priest and Horner, 1980). Evidently the asbestos fiber bundles were found to produce hazardous-size respirable particles capable of causing lung disease (Fig 5-20a).

Alternative nonasbestos ring liner materials fall into three categories: ceramic (aluminum silicate), cellulose (paper), and a ceramic-cellulose combination (Naylor et al, 1987). The microstructure of these materials varies (Figs 5-20b to d). Furthermore, the relative safety of the ceramic ring liners remains uncertain, because aluminum silicate also appears capable of producing hazardous-size respirable particles (Naylor et al, 1987).

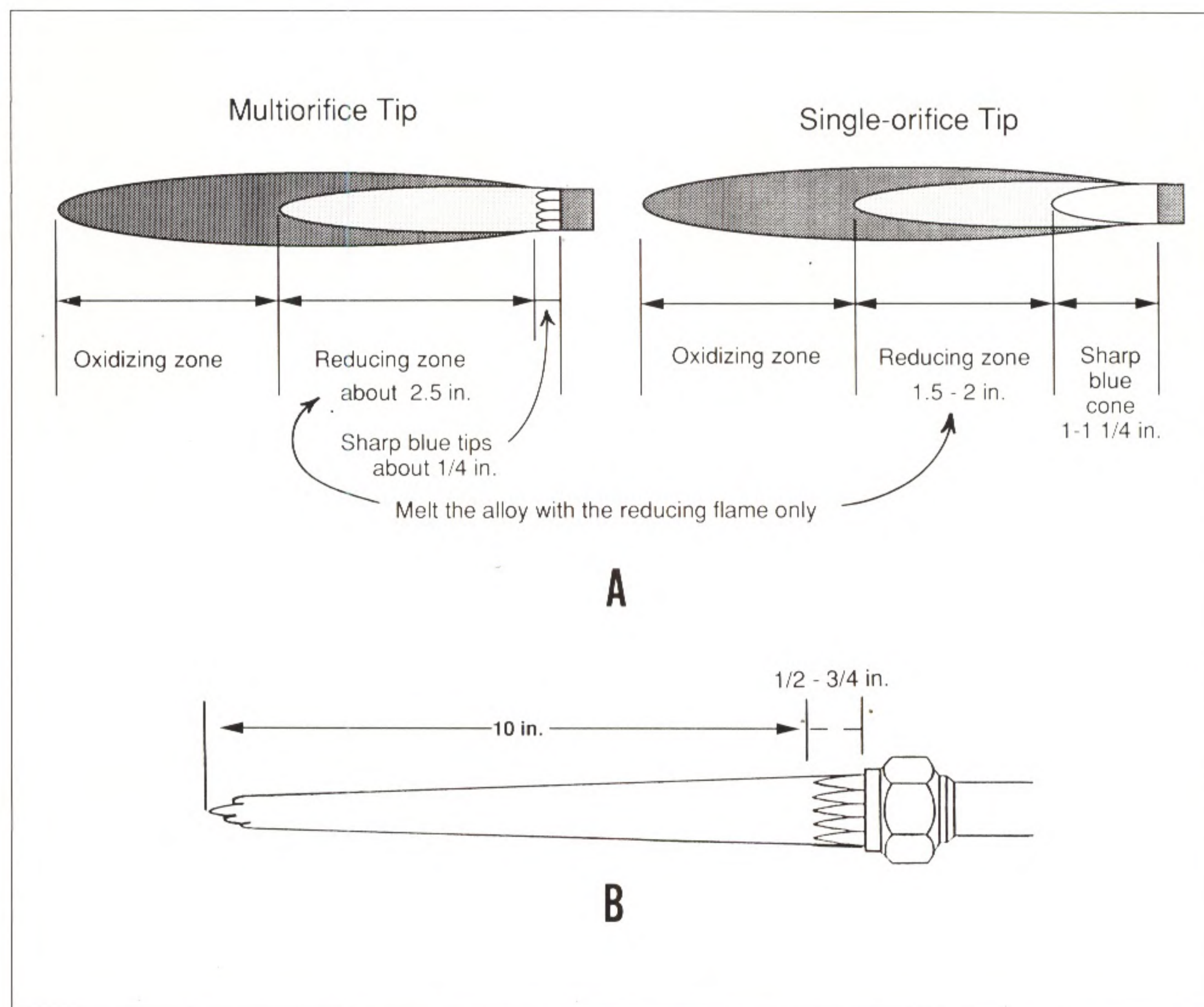


Fig 5-21 (A) The proper flame patterns for a multiorifice and a single-orifice tip will vary. (B) Base metal alloys require a flame configuration different from that of noble alloys. In fact, some manufacturers may recommend lengthening the inner blue cover up to three quarters of an inch.

Investing technique

Follow the same basic technique used to produce castings with crown-and-bridge alloys, but use high-heat investments. Ask your alloy manufacturer for recommended investments and liquid/powder ratios and dilution of investment special liquid (if appropriate).

up to 1,600°F for base metal alloys and between 1,400°F and 1,600°F for noble metal alloys. Refer to the instructions on the alloy package for the high temperature setting and burnout time for each specific alloy. The recommended temperature rate of rise for the burnout furnace ranges from 20°F/min to 50°F/min.

Wax elimination (burnout) technique

The burnout technique will vary for alloys of different compositions. High temperature settings will range

Melting and casting techniques

Assuming a case has been properly sprued, invested, and burned out, the next crucial steps involve

melting and casting. A poorly adjusted torch or improper casting method can ruin all your efforts up to this point. The following topics have been included to help you better understand the casting process.

Casting torch selection

There are two types of torch tips to choose from when selecting casting equipment: multiorifice and single orifice (Naylor, 1986) (Fig 5-21). The tip most widely used for metal ceramic alloys is probably the multiorifice type. Its main advantage is the distribution of heat over a wide area for more uniform heating of the alloy, which is particularly helpful in casting high-fusing base metal alloys. The single-orifice tip (Fig 5-21, A) may concentrate more heat in one area, but the area is smaller than that produced by the multiorifice tip (Fig 5-21, A and B).

Choice of fuels

The three fuel sources that merit specific mention are: acetylene, natural gas, and propane (Dental Laboratory Manual, 1982).

1. *Acetylene*. This colorless gas has a distinctive garlic-like odor. It will burn in air and can generate a flame approaching 3,000°F. Unfortunately, acetylene is usually contaminated with carbon and other elements, so it should not be used to melt metal ceramic alloys.
2. *Natural gas*. This fuel is the by-product of the "natural" decomposition of organic matter in the ground. When mixed with air, the natural gas flame approaches a temperature of 2,200°F. Replacing air with oxygen enables natural gas to attain temperatures required to melt the high-fusing noble and base metal alloys. Natural gas is an acceptable fuel source, although it is not ideal. Inadequate pressure in gas lines, fluctuations in pressure levels, water contamination, and variations in composition among gas companies are some of the problems encountered by natural gas users. Nonetheless, natural gas is a widely used fuel.
3. *Propane*. The problems with natural gas are avoided when using bottled propane gas. The constant, regulated mixture of pure, uncontaminated propane and oxygen provides a clean, consistent burn leading to a more ideal melt.

Casting equipment

Noble and base metal alloys can be cast with either a torch in a centrifugal casting unit or in an induction casting machine. Irrespective of the type of equipment selected, the lower density alloys require an additional wind of the casting arm to ensure adequate casting pressure.

Casting crucibles

Either zircon-alumina or quartz casting crucibles are recommended for noble and base metal ceramic alloys. The clay-type crucibles will break down when exposed to the high temperatures required to melt metal ceramic alloys, possibly contaminating the melt (Cascone, 1977). Carbon crucibles are well suited for gold-based alloys but are a ready source of carbon contamination for palladium-, nickel-, and cobalt-based metals. The contamination takes the form of carbide formation that can embrittle these alloys.

After selecting the appropriate type of casting crucible, preheat it in the oven with the casting ring. Preheating the crucible prevents spalling (cracking) and prolongs the crucible's life. Never cast different alloys in the same crucible as this will cause alloy contamination. Instead, use color-coded crucibles (eg, from Belle de St Claire) or carve the alloy name in each crucible for identification (Fig 5-22). Do not use an asbestos liner in the crucible or flux the molten alloy.

Electric casting machines

Electric casting machines with carbon crucibles are appropriate for gold-based alloys, but they are generally not recommended for palladium-, nickel-, and cobalt-based alloys because of the potential for carbon contamination. As indicated previously, exposure to carbon can weaken the cast restoration.

Air-abrasive (blasting) compounds

Commercially available abrasive compounds such as aluminum oxide (Al_2O_3), general purpose blasting compound, and glass beads can remove casting investment and surface oxides. A 50- μm grit, non-recycled aluminum oxide abrasive (white color) is commonly suggested for air-abrading porcelain-bearing surfaces and dental porcelain (Winings, 1981) (Fig 5-23).

Aluminum oxides that are other than white may

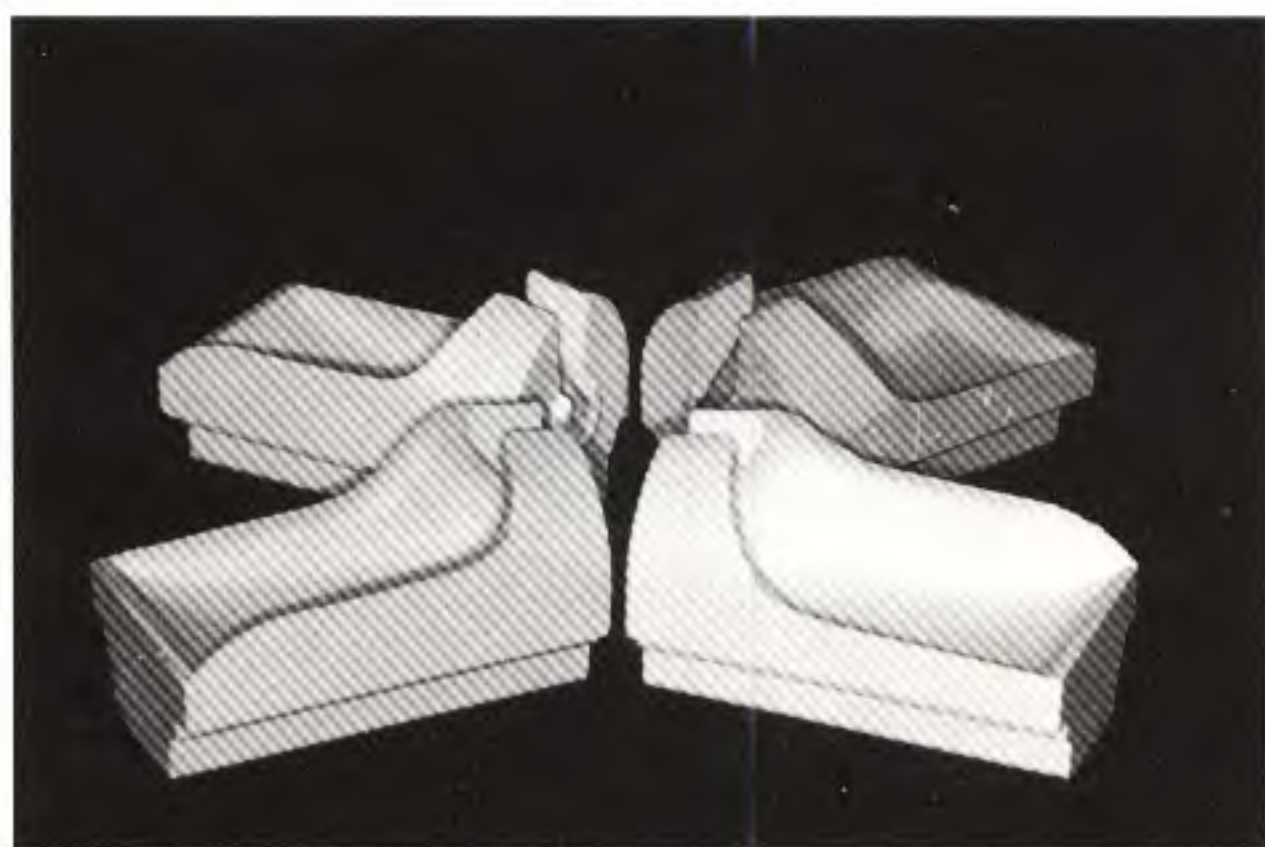


Fig 5-22 Zircon-alumina crucibles are more durable than the quartz type. Belle de St Claire color-coded zircon-alumina casting crucibles permit assignment of different alloys to specific colors.

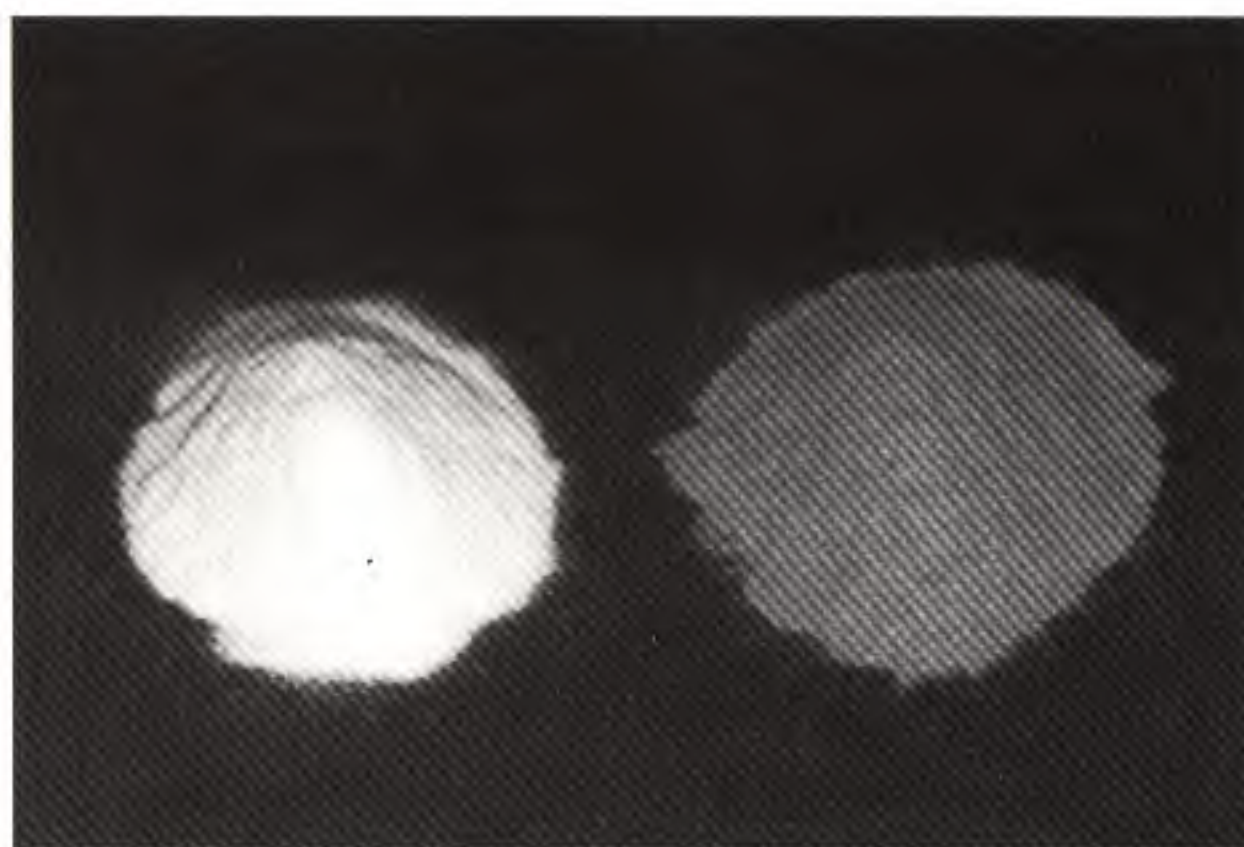


Fig 5-23 Pure aluminum-oxide (*left*) is white and is less likely to contain contaminants as all-purpose abrasives (*right*).

contain impurities such as iron. Run a magnet through the material if you suspect it is contaminated.

The laws of casting

Casting is both an art and a science governed by numerous rules, or "laws." Personal interpretation of these laws is demonstrated in a technician's approach to the procedure, that is, the art of casting. Integrating the theoretical principles supporting this art enables you to blend science with art in dental technology. At times, casting problems can be attributed to poor casting technique and/or a failure to adhere to one or more of the basic principles (laws) of casting.

An important foundation of the laws of casting is that every casting contains porosity attributed to solidification shrinkage. Porosity invariably occurs in the area of the casting that is last to solidify. The challenge faced by the technician is to use knowledge of the science of casting to locate the porosity in an area of the spruing system away from the restoration(s). Building on the earlier work of Ingersoll and Wandling (1986), I formulated an expanded set of 17 separate recommendations for spruing, investing, burnout, and melting and casting procedures. Collectively, these guidelines are referred to as the *laws of casting*.

The three-unit fixed partial denture wax pattern will be used to illustrate several key points related to the spruing and investing procedure (Figs 5-24 to 5-32).

Spruing (Figs 5-24 to 5-29)

The 1st law of casting

Attach the pattern sprue former to the thickest part of the wax pattern (Fig 5-26). As the molten alloy moves from the reservoir to the pattern margins it should flow from areas of greater volume to areas of lesser volume (ie, the margins). Lute the pattern sprue former to the most practical portion of the occlusal/incisal surface. Except for thin anterior copings, do not place a sprue former in a cutback area if an adjacent, fully contoured cusp is available. Molten metal flowing from a thin area to a thicker region (full waxup) may solidify before the mold is completely filled. When using indirect spruing, be sure to select the appropriate-size prefabricated sprue former (Figs 5-25 and 5-27).

The *penalties* for not obeying this law are: COLD SHUTS, SHORT MARGINS, and INCOMPLETE CASTINGS.

The 2nd law of casting

Orient wax patterns so all the restoration margins will face the trailing edge when the ring is positioned in the casting machine. To identify that orientation, add a wax dot to the crucible former so you know how to place the ring in the casting cradle correctly after the patterns have been invested (see Figs 5-6a and b).

The *penalties* for not obeying this law are: COLD SHUTS and SHORT MARGINS.



Fig 5-24 The three-unit fixed partial denture substructure (from chapter 4) after completion of the wax cutback.



Fig 5-25 The Ready Sprue has a connector bar with an adequate diameter and length for this fixed partial denture wax pattern.

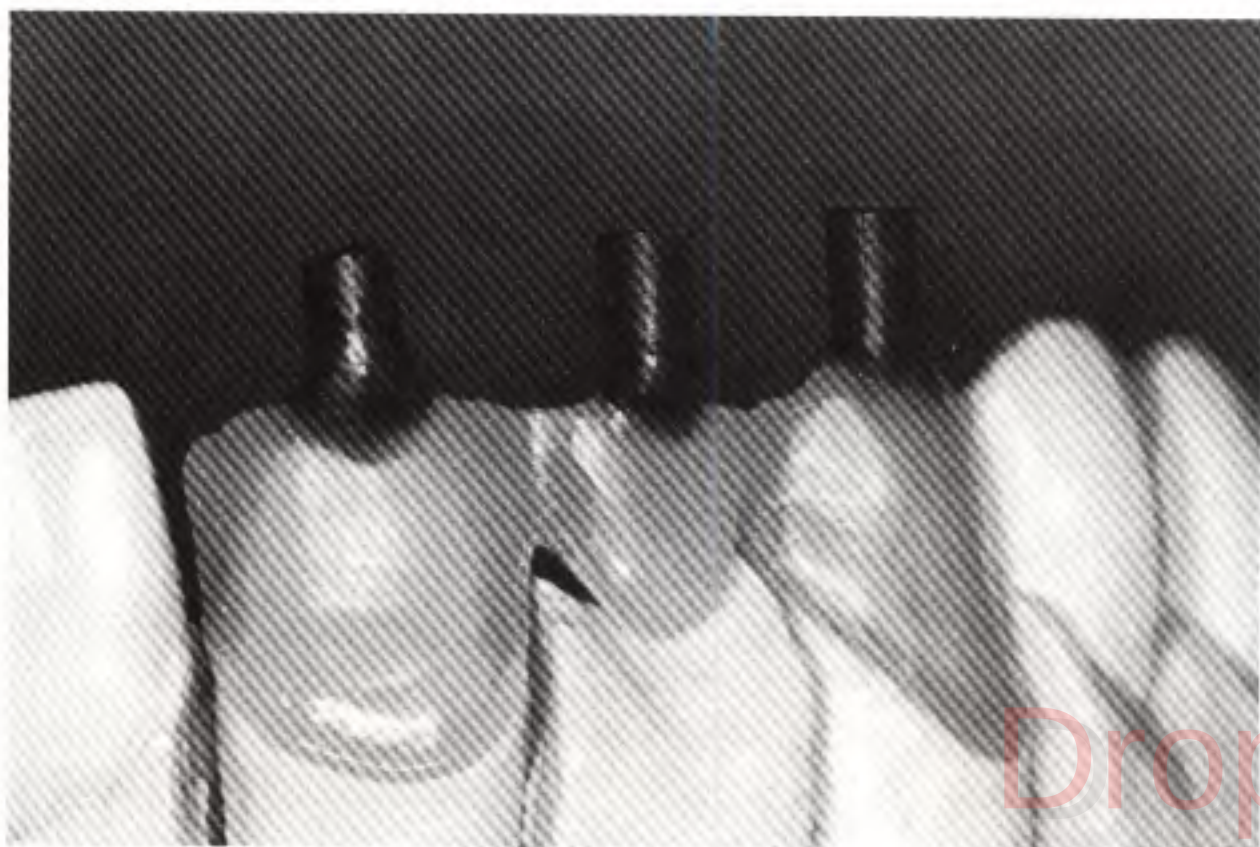


Fig 5-26 Pattern sprue formers are selected and luted to each wax pattern.



Fig 5-27 The indirect sprue pattern is luted to the pattern sprues. Note how the Ready Sprue has been shaped to the curvature of the arch.

The 3rd law of casting

Position the wax patterns in a "cold zone" of the investment mold and the reservoir in the "heat center" of the casting ring. The coolest parts of the mold (cold zones) are at the end of the ring and along the ring periphery. The hottest portion of the casting ring is located near the center of the ring (the "heat center") (see Fig 5-10). Limit the amount of investment covering the patterns to no more than $\frac{1}{4}$ in. (6 mm) and position the reservoir in the heat center (see Figs 5-3 and 5-10b). Adherence to this law increases the likelihood that casting porosity will occur in the reservoir rather than in the restoration.

The *penalty* for not obeying this law is: SHRINK-AGE POROSITY in the restorations.

The 4th law of casting

A reservoir must have sufficient molten alloy to

accommodate the shrinkage that occurs within the restorations. Alloy that fills the restorations will solidify first. As that molten metal solidifies, it shrinks and creates a vacuum. For a complete casting, the vacuum must be able to draw additional metal from an adjacent source—the reservoir. A runner (connector) bar can be an effective reservoir if it is equal to or greater than the thickest cross-sectional area of the wax pattern (see Figs 5-5, 5-10, and 5-25).

The *penalties* for not obeying this law are: SHRINK-AGE POROSITY and/or SUCK-BACK POROSITY.

The 5th law of casting

Do not cast a button if a connector (runner) bar, or other internal reservoir, is used (see Fig 5-15). With indirect spruing, the largest mass of metal should be the reservoir (see Fig 5-10b). A button is counterproductive because it can draw available molten alloy

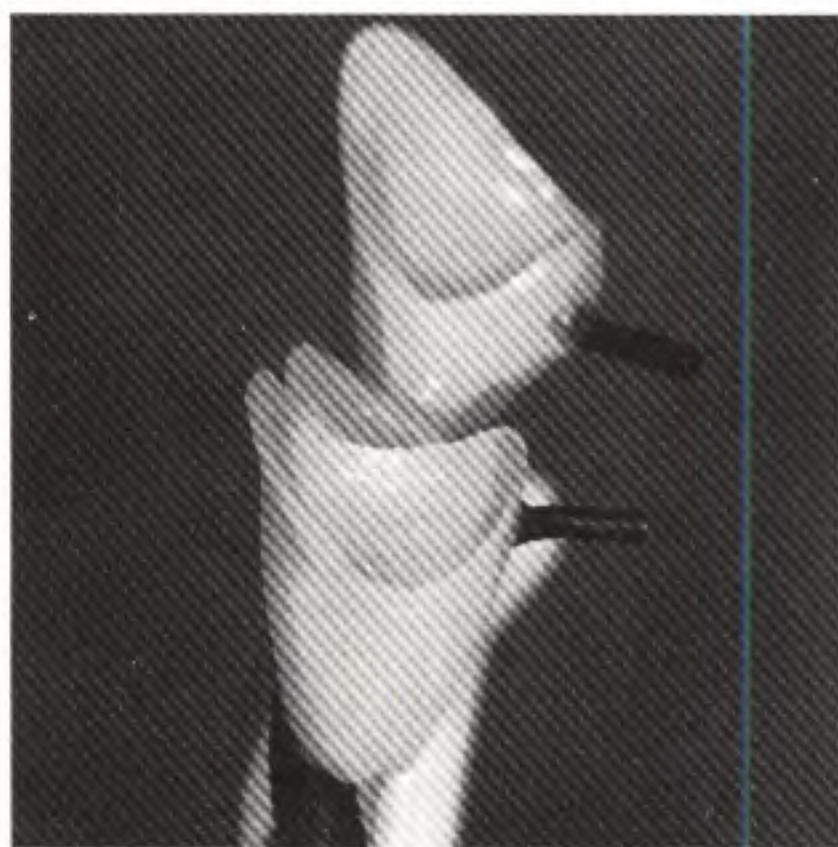


Fig 5-28 Attach 18-gauge wax to the lingual surfaces (optional) to serve as handles in the cast framework, thereby protecting the delicate metal margins.



Figs 5-29a and b Apply a thin layer of debubblizer (wax pattern cleaner) to the wax patterns and indirect spruing system and allow it to dry thoroughly before investing. Then weigh the assembly again and determine the amount of alloy needed (see Appendix C).

from the bar, shift the heat center and reduce the feed of that metal to the restorations (see Fig 5-13). Likewise, the wax patterns should not be larger than the connector bar, if the bar is to act as a true reservoir (see Figs 5-10b and 5-14). Weigh the sprued patterns and use the wax pattern-alloy conversion chart (see Appendix C) to determine the amount of alloy needed (Figs 5-29a and b).

The *penalties* for not obeying this law are: SHRINKAGE POROSITY (and potential DISTORTION during porcelain firing) and SUCK-BACK POROSITY.

The 6th law of casting

Turbulence must be minimized, if not totally eliminated. Pathways for the flow of metal should be smooth, gradual, and without impediments. Eliminate sharp turns, restrictions, points, or impingements that might create turbulence and occlude air in the casting. Restrictions, or constrictions, can accelerate the

metal's rate of flow and abrade the mold surface (mold wash) (Ingersoll and Wandling, 1986).

The *penalties* for not obeying this law are: VOIDS in the casting and/or SURFACE PITTING. VOIDS can be created by the occlusion of air from turbulent metal flow. MOLD WASH can remove investment particles from the mold's inner surface and carry them ahead of the alloy. These entrapped particles can produce SURFACE PITS and incomplete margins.

The 7th law of casting

Select a casting ring of sufficient length and diameter to accommodate the patterns to be invested. The casting ring should permit the patterns to be $\frac{1}{4}$ in. apart and $\frac{1}{4}$ in. from the top of the investment with a minimum $\frac{3}{8}$ in. of investment between them and the ring liner (see Fig 5-3). If too little investment covers the wax patterns, the alloy is more likely to break through the mold. Too much invest-



Fig 5-30 A casting with fins created either by excess wax pattern cleaner or by improper heating of the mold.



Fig 5-31 After vacuum mixing the investment, paint the inside of the individual wax retainers to prevent the entrapment of air and ensure complete wetting of the patterns.



Fig 5-32 Once the entire wax pattern is covered by investment, place the casting ring in the crucible former and fill the casting ring with enough investment to cover the pattern.

ment over the waxups may locate the wax patterns too close to the heat center of the mold and impair the escape of gases.

The *penalties* for not obeying this law are: MOLD FRACTURE, CASTING FINS, and SHRINKAGE POROSITY.

Investing and wax elimination (burnout) (Figs 5-29 to 5-33)

The 8th law of casting

Increase the wettability of the wax patterns. A wetting agent should be brushed or sprayed on the patterns and dried before investing (Fig 5-29a). A clean wax surface better enables the casting investment to wet the patterns more completely. Apply the liquid wax pattern cleaner sparingly and let it dry thoroughly before investing. Too much wetting agent can create a surface film that can dilute and weaken the investment in that area and produce bubbles or fins on the casting (Fig 5-30).

The *penalty* for not obeying this law is: BUBBLES on the surface of the casting as a result of the entrapment of air (too little wetting agent) or excess liquid (too much wetting agent).

The 9th law of casting

Weigh any bulk investment and measure the investment liquid for a precise powder-liquid ratio.

The correct proportions of powder to liquid and any dilution of the (special) liquid with distilled water should be established for each alloy. A thick mix of investment (reduced liquid) increases investment expansion and produces loose-fitting castings. Too much liquid (special liquid and distilled water, if any)

results in a thinner mix and less expansion with tighter-fitting castings. Using all special liquid provides more expansion but reduces working time compared to a 50:50 dilution of the special liquid and distilled water.

The *penalty* for not obeying this law is: ILL-FITTING CASTINGS.

The 10th law of casting

Eliminate the incorporation of air in the casting investment and remove the ammonia gas by-product of phosphate-bonded investments by mixing under vacuum. Vacuum mixing removes more air and gas than hand spatulation (Figs 5-31 and 5-32). Areas of the mold that contain dense, bubble-free investment will expand differently from sections that contain large voids (entrapped air). The mixing time will depend on the type of investment used and the mixing speed (slow-speed versus high-speed mixing).

The *penalties* for not obeying this law are: small NODULES on the casting, a WEAK MOLD, and DISTORTION of the casting.

The 11th law of casting

Allow the casting investment to set completely before initiating the burnout procedure. If setting is not complete at the time a ring is placed in the oven, the mold may be weak and unable to withstand steam expansion during burnout. The investment could fracture as a consequence. For best results, burnout should be initiated only after the recommended setting time.

The *penalties* for not obeying this law are: MOLD CRACKING/BLOWOUT or FINS on the casting.

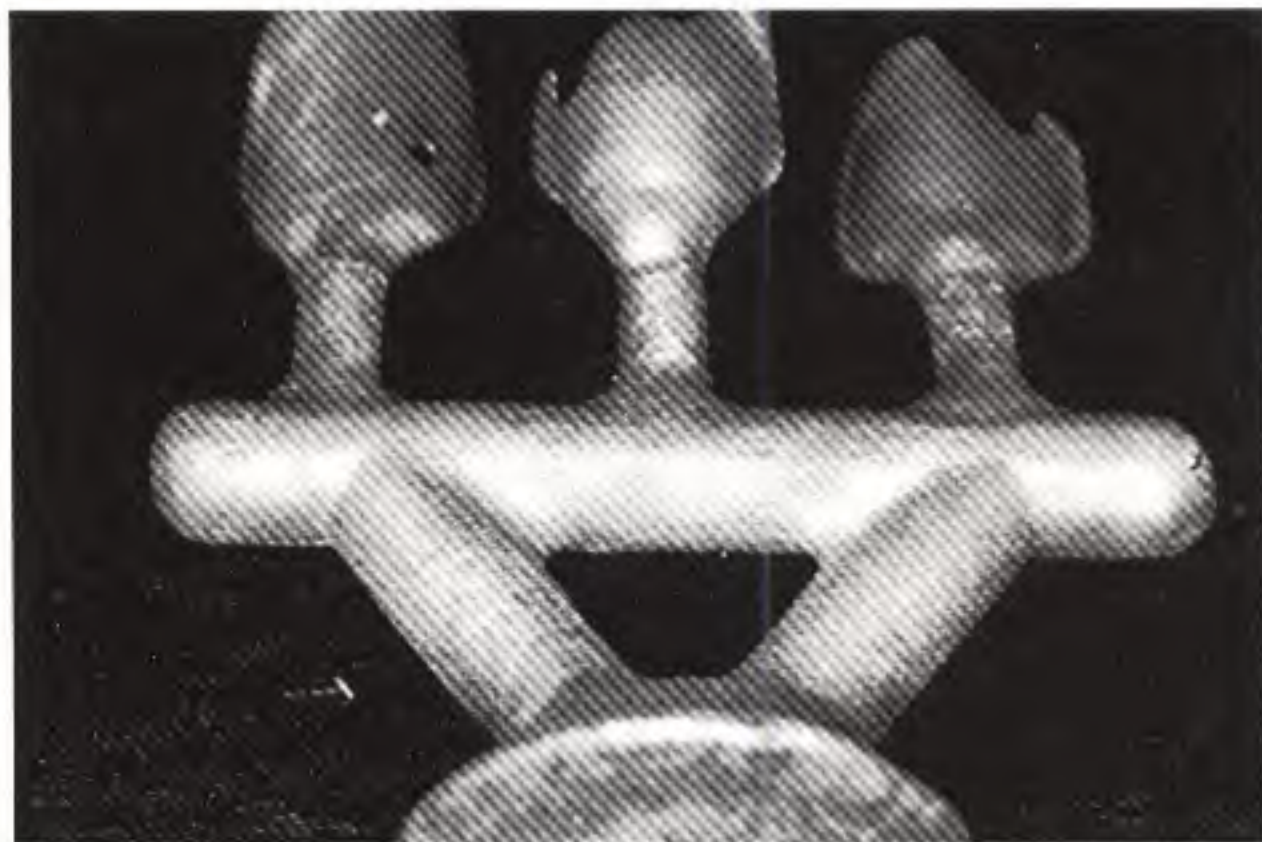


Fig 5-33 When the connector bar is too small and a button is cast, the connector bar may be adequately cast but the restorations will be incomplete. Note the absence of porosity on the underside of the bar, an indication that the button supported the bar rather than the patterns.

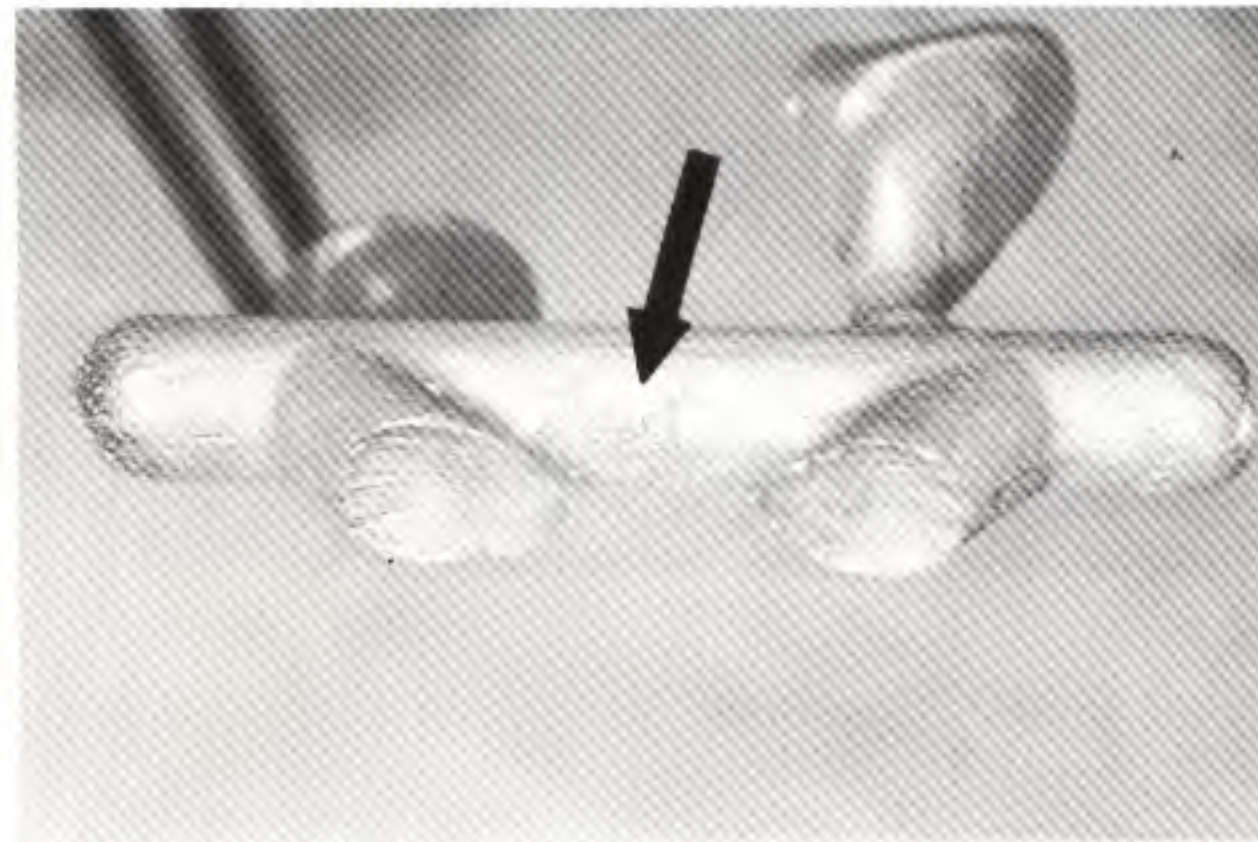


Fig 5-34 When no button is cast and the reservoir is the last portion of the casting to solidify, the porosity should appear on the underside of the bar (arrow), away from the restoration (cast in the nickel-chromium-beryllium alloy, Biobond II).

The 12th law of casting

Use a wax elimination (burnout) technique that is specific for the type of patterns involved (wax versus plastic) and recommended for the particular type of casting alloy selected. Plastic sprues need to be heated slowly so they can soften gradually and not exert pressure on the mold, so use a two-stage burnout (Tombasco and Reilly, 1987). Slow the rate of rise to permit the heat to move through the investment for uniform expansion. If burnout is incomplete, the spruing system channels may be blocked by wax or plastic residue (carbon) and, on casting, air cannot escape completely when the metal enters the mold (Naylor, 1990a; Tombasco and Reilly, 1987). Therefore, use at least a 30-minute heat-soaking at 800°F for the first burnout stage.

The *penalties* for not obeying this law are: COLD SHUTS, SHORT MARGINS, COLD WELDS, MOLD CRACKS, and/or CASTING FINS.

Melting and casting

The 13th law of casting

Adequate heat must be available to properly melt and cast the alloy (Myers, 1936). The selected heat source should be capable of melting the alloy to the point of sufficient fluidity. Prolonged heating, caused by an improperly adjusted torch, can prevent the alloy from attaining the fluidity needed for complete mold filling and compensation for heat loss. Too much heat, or too high a temperature, can burn off minor

alloying elements through vaporization and/or oxidation (burned metal).

The *penalties* for not obeying this law are: COLD SHUTS, SHORT MARGINS, and COLD WELDS (too little heat), or ROUGH CASTINGS and INVESTMENT BREAKDOWN (too much heat).

The 14th law of casting

When torch casting, use the “reducing zone” of the flame to melt the alloy and not the oxidizing zone (see Fig 5-21). An improperly adjusted torch can add carbon or oxygen to the alloy while heating. A melt achieved by the exclusive use of the REDUCING ZONE minimizes the likelihood of metal oxidation and gas absorption and ensures a proper melt.

The *penalties* for not obeying this law are: GAS POROSITY and/or a change in the alloy's COEFFICIENT OF THERMAL EXPANSION (due to alloy contamination).

The 15th law of casting

Provide enough force to cause the liquid alloy to flow into the heated mold. Adjust the casting machine to the requirements of each alloy. Lower-density metals generally need four winds of a centrifugal casting arm as compared to higher-density, gold-based alloys. Do not overwind.

The *penalties* for not obeying this law are: COLD SHUTS, SHORT MARGINS, COLD WELDS (insufficient force), or MOLD FRACTURE and FINS (too much force).

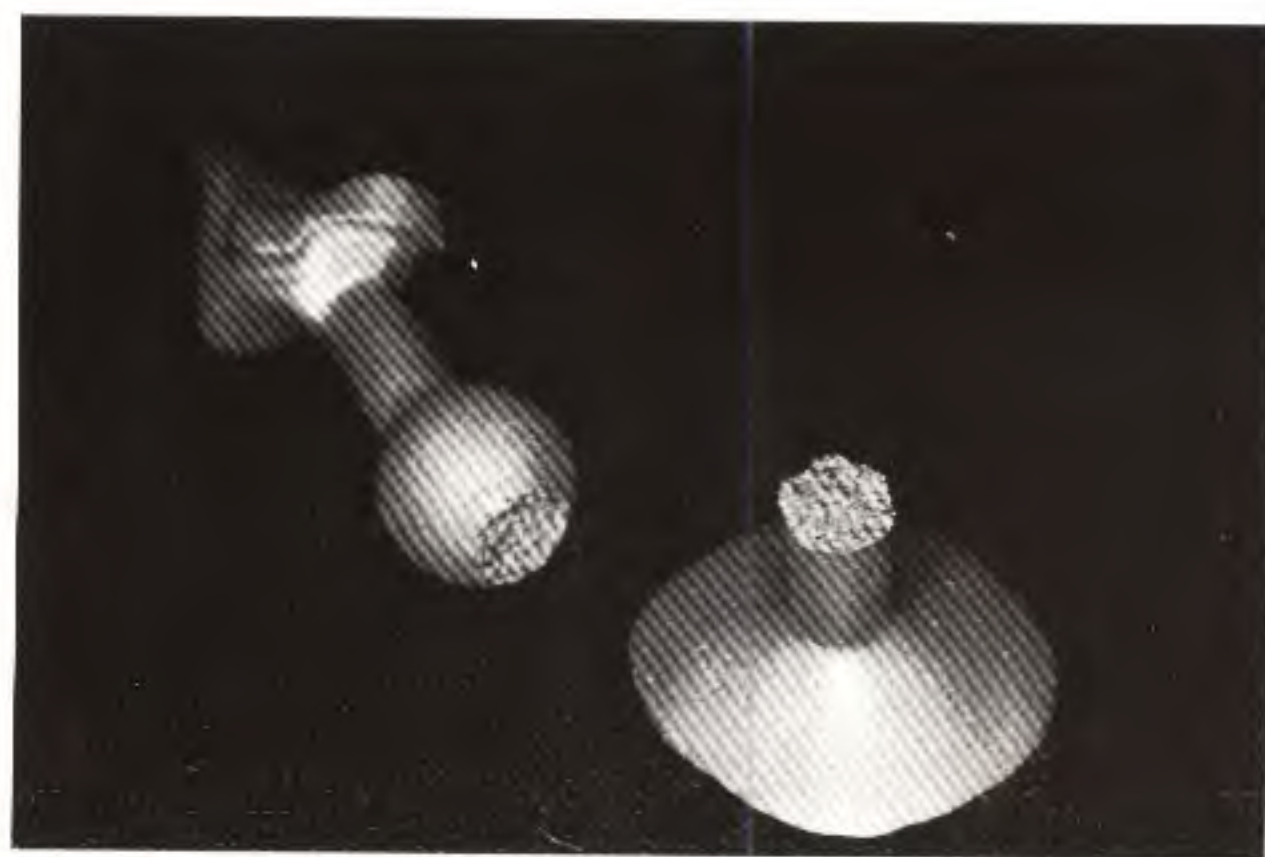


Fig 5-35 In direct spruing, when alloy solidification occurs in the area of the reservoir ball, the porosity should appear on the side opposite the restoration.

The 16th law of casting

Cast toward the margins of the wax patterns. Place the heated ring in the casting cradle using the orientation dot so the pattern margins face the trailing edge (the 2nd law). In a centrifugal casting machine the metal will flow downward and to the right, taking advantage of the centrifugal, rotational, and gravitational forces on the molten alloy (Ogura et al, 1981; Ingersoll and Wandling, 1986).

The *penalties* for not obeying this law are: COLD SHUTS, SHORT MARGINS, and otherwise INCOMPLETE CASTINGS.

The 17th law of casting

Do not quench the ring immediately after casting. Allow the alloy and the investment to cool to room temperature. Uneven cooling and shrinkage between alloy and investment can apply tensile forces to the casting (Cascone, 1976). After casting, the alloy may not possess sufficient strength to resist these forces and the restoration could tear, if quenched.

The *penalty* for not obeying this law is: HOT TEARS in the restoration.

Analyzing casting failures

Despite concerted efforts to follow the recommended procedures outlined in this chapter, casting failure and mishaps are bound to occur in the dental laboratory (Fig 5-33). Errors in technique and, on occasion, material failures can unexpectedly result in unsatisfactory castings. By standardizing your technique and paying strict attention to each step involved in spruing, investing, and casting, it is often possible to control the location of the solidification shrinkage and

to minimize the number of actual miscasts (Figs 5-34 and 5-35). Proper storage and rotation of casting investment inventories will help ensure consistent and accurate performance.

When casting failures do occur, you should troubleshoot each miscast to diagnose the cause or causes of the problem so corrective measures may be taken before you make additional castings. Mackert (1988) reported one of the most comprehensive methods to assess casting failures from preparation of a custom impression tray to waxing, spruing, investing, burn-out, and ultimately to melting the alloy.

Summary

The very nature of the differences in metal ceramic alloys, compared to conventional gold-based crown-and-bridge metals, necessitates certain changes in your waxing, spruing, and investing techniques. Whether it is in understanding the demands of low-density alloys, selecting an appropriate spruing technique, or determining how to properly cast a high-fusing alloy, it helps if you understand the theoretical aspects of waxing, spruing, and investing. This chapter was intended to present the fundamental principles of these technical procedures which are brought together in the *laws of casting*.

Before proceeding directly to the discussion of metal finishing (chapter 7), you must first understand how dental porcelain bonds to a metal ceramic alloy (chapter 6). In this way, it is hoped that you will gain a better appreciation for the materials, procedures, and techniques used to prepare the cast restoration to receive porcelain and maintain the porcelain-metal bond. Turn to chapter 6 for a discussion on the theories of porcelain-metal bonding.

How Does Dental Porcelain Bond to Metal?

Introduction

No text on the metal ceramic restoration would be complete without some mention of how dental porcelain "bonds" or "adheres" to its underlying metal substructure. The exact mechanisms responsible for bonding are unknown; however, there are several theories believed to provide acceptable explanations for the interrelationship at the porcelain-metal interface. Possessing an understanding of these theoretical considerations of porcelain bonding is just as important to the success of metal ceramic restorations as mastering the technical skills of porcelain application.

Use of the word bond might imply that the relationship between dental porcelain and metal is a purely chemical one (Webster, 1982). Indeed, chemical bonds do play a primary role in the bonding process, but several nonchemical mechanisms are also thought to contribute to the "bonding" of dental porcelain to its underlying metal substructure.

Whether this attachment between porcelain and metal is chemical or mechanical in nature, or both, is more of an academic point. Knowing how to establish and then maintain an optimum porcelain-to-metal bond is far more significant from a technical standpoint.

Mechanisms of porcelain-metal attachment

At least four theories have been proposed to explain the processes that lead to porcelain-to-metal bonding: (1) van der Waals forces (Lacy, 1977), (2) mechanical retention, (3) compression bonding, and (4) direct chemical bonding (Lacy, 1977; McLean, 1980; Murakami and Shulman, 1987). Not everyone accepts all four of these suggested explanations, yet most experts generally agree that the chemical form

of attachment is the predominant and most important mechanism (Lacy, 1977).

van der Waals forces

The attraction between charged atoms that are in intimate contact yet do not actually exchange electrons is derived from van der Waals forces (Lacy, 1977). These secondary forces are generated more by a physical attraction between charged particles than by an actual sharing or exchange of electrons in primary (chemical) bonding (Fig 6-1). Van der Waals forces are generally weak, because nearly all the positive and negative charges present in these atoms are satisfied in a single molecule (Garret et al, 1972). Only minimal attraction exists between the electrons and nuclei of atoms in one molecule and the nuclei and electrons of atoms in an adjacent molecule.

It is also believed that bonding entails some measure of true adhesion based on the extent to which the metal substructure is wetted by the softened dental porcelain (Lacy, 1977). The better the wetting of the metal surface, the greater the van der Waals forces. Furthermore, porcelain's adhesion to metal can be diminished or enhanced by alterations in the surface character (texture) of the porcelain-bearing surface on the substructure. For example, a rough, contaminated metal surface will inhibit wetting and reduce the van der Waals bond strength. On the other hand, a slightly textured surface, created by finishing with uncontaminated aluminum oxide (Al_2O_3) abrasives and followed by air abrasion (blasting) with 50- μm aluminum oxide, reportedly will promote wetting by the liquid porcelain. Improved wetting is then accompanied by an increase in adhesion through van der Waals forces.

However, even under optimum conditions, van der Waals forces undoubtedly are only minor contributors to the overall attachment process.

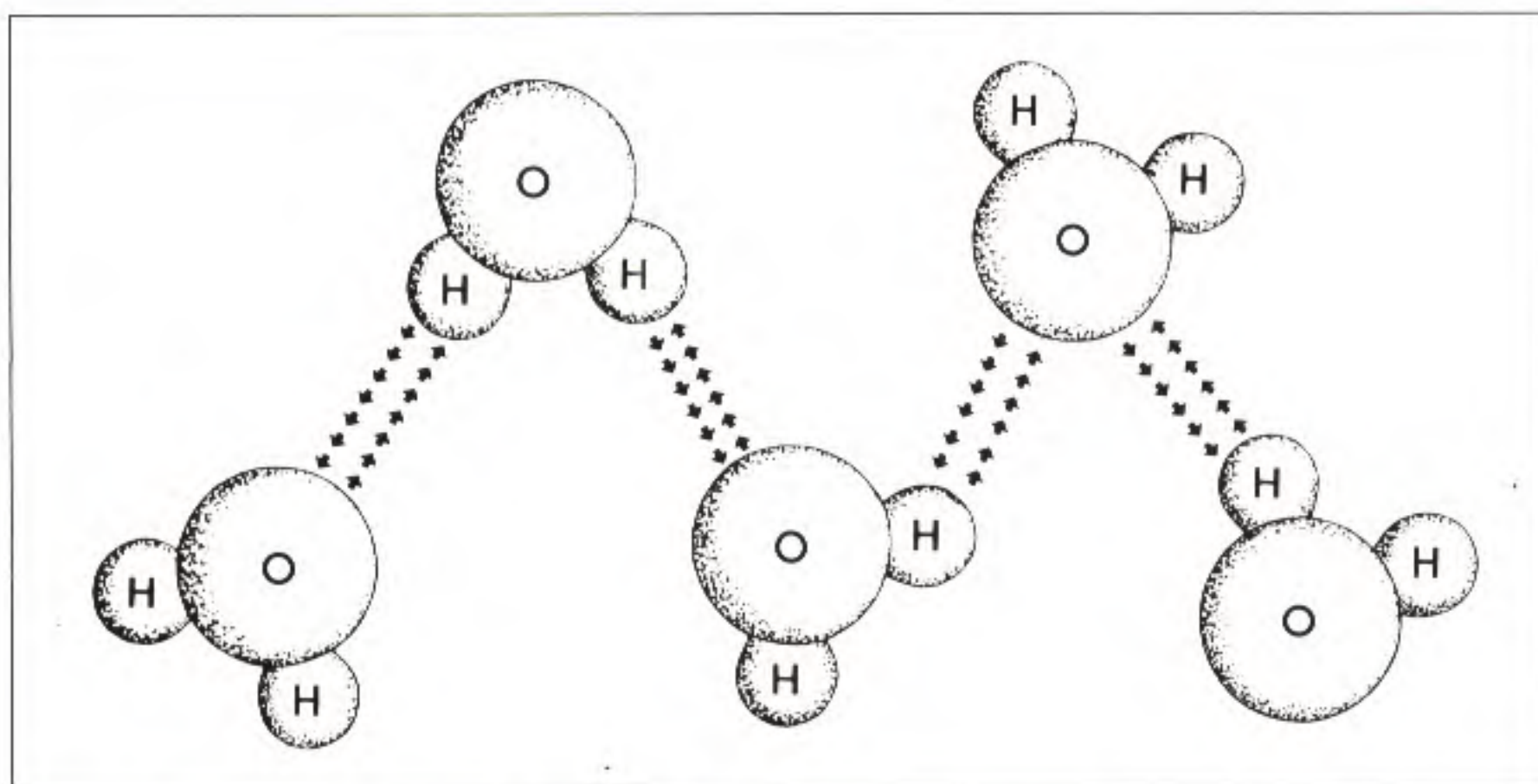


Fig 6-1 The attraction between the positively charged hydrogen (H) portion of one molecule and the negatively charged oxygen (O) of an adjacent molecule is one of the best examples of van der Waals forces.



Fig 6-2 A scanning electron micrograph (SEM) of a finished metal coping illustrating the numerous surface irregularities that exist on a metal substructure to provide mechanical retention of the fired porcelain.

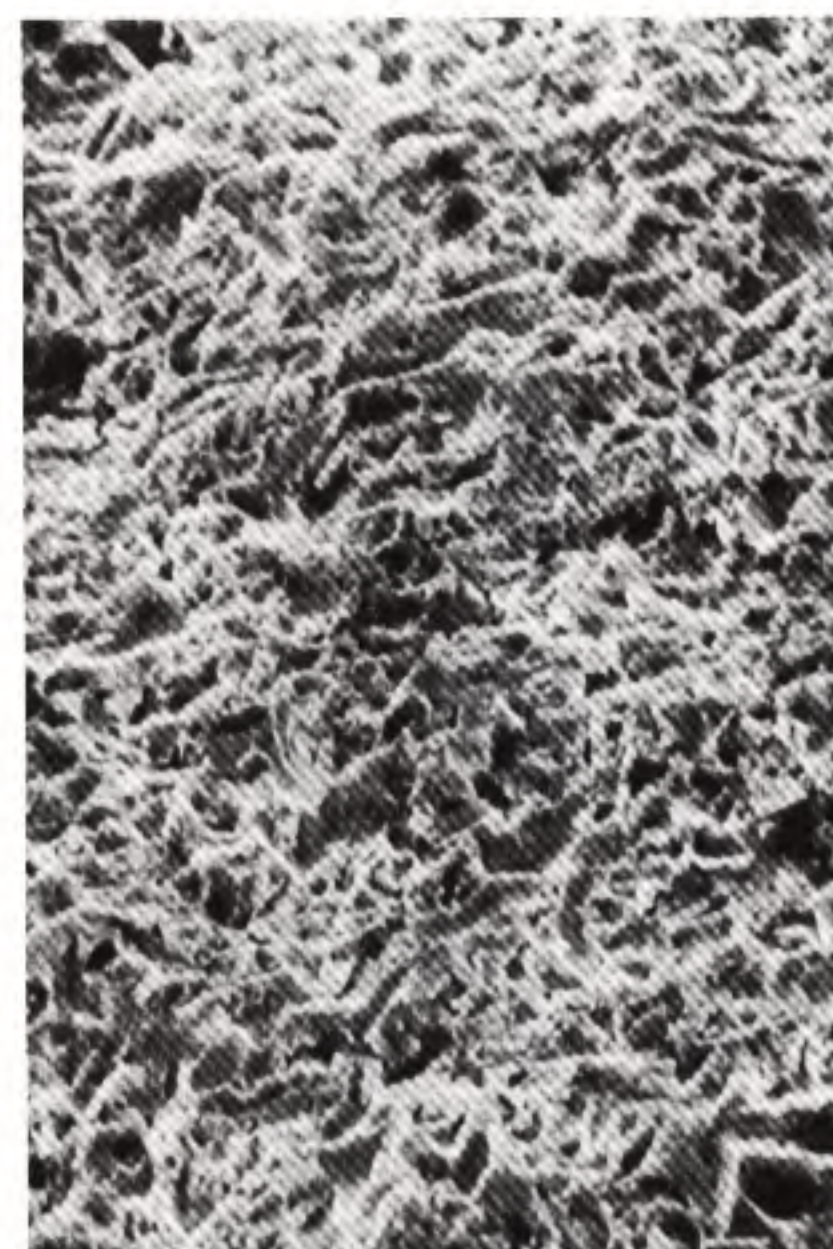


Fig 6-3 Air-abrading the porcelain-bearing surfaces with aluminum oxide removes surface contaminants and oxides but leaves a matte finish for improved porcelain bonding. The surface irregularities will also provide micromechanical retention.

Mechanical retention

The porcelain-bearing area of a metal casting contains many microscopic irregularities into which opaque porcelain may flow when fired (Fig 6-2). Air-abrading the metal with aluminum oxide is believed to enhance mechanical retention further by eliminating surface irregularities (stress concentrations) while increasing the overall surface area available for bonding (Fig 6-3).

The mechanical attachment of porcelain to metal is established in much the same manner as a painter preparing a house for its first coat of paint. After finishing and cleaning the wood surface, a thin coat of

primer paint is applied to seal the wood and initiate the paint-wood bond. Once the primer layer has dried the painter can add the final applications of paint in the chosen color. Opaque porcelain functions much like a primer paint, because it fills the many surface irregularities on the metal, initiates the porcelain-metal bond, and serves as the foundation of color development.

Despite its presence, mechanical retention's contribution to bonding may be relatively limited. Dental porcelain does not require a roughened area to bond to metal. In fact, porcelain will fuse to a well-polished surface (Lacy, 1977), but some surface roughness is effective in increasing bonding forces (Yamamoto,

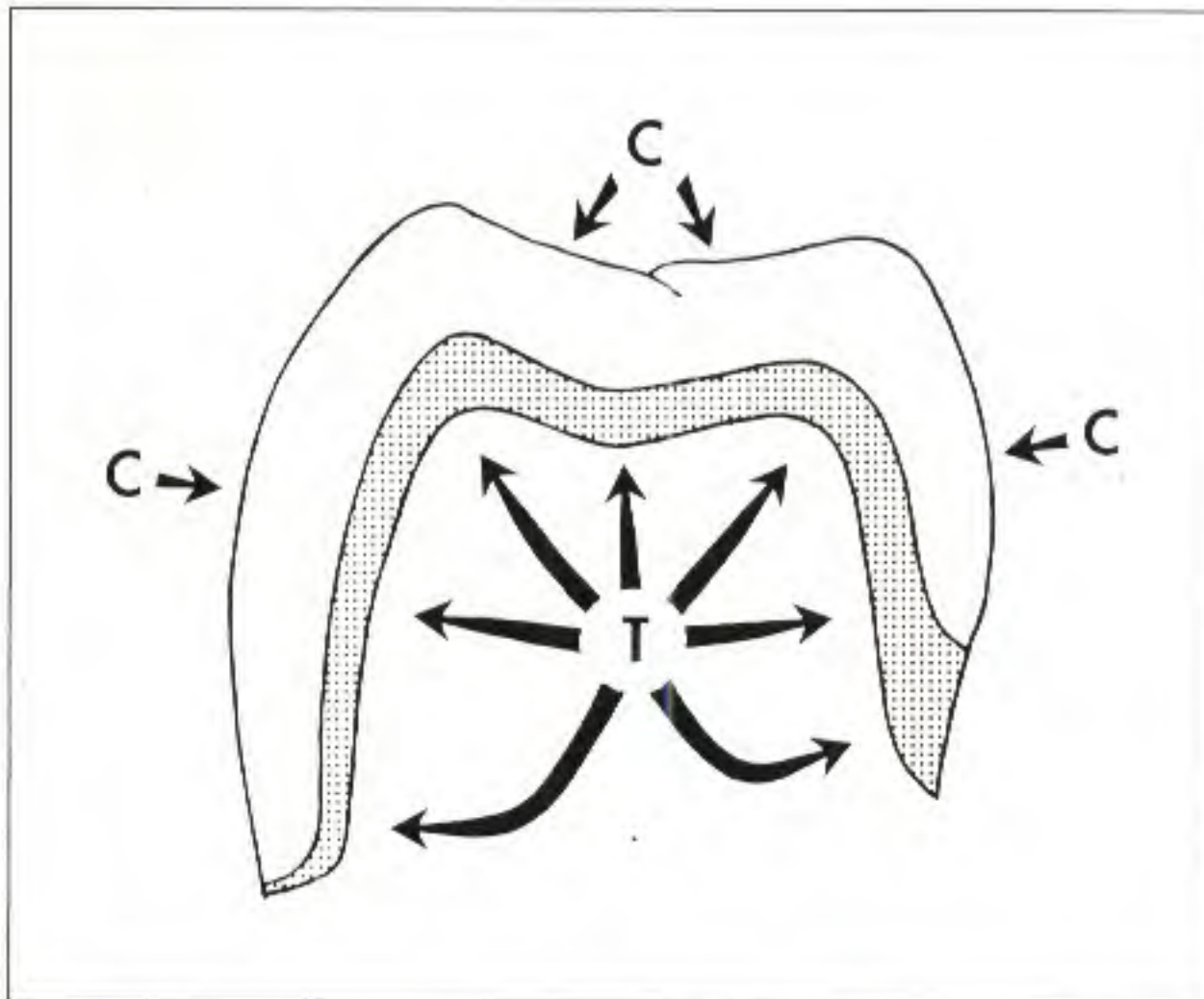


Fig 6-4 In a restoration with full-porcelain coverage, the metal is probably under tension (*T*) and ideally the porcelain is under compression (*C*).

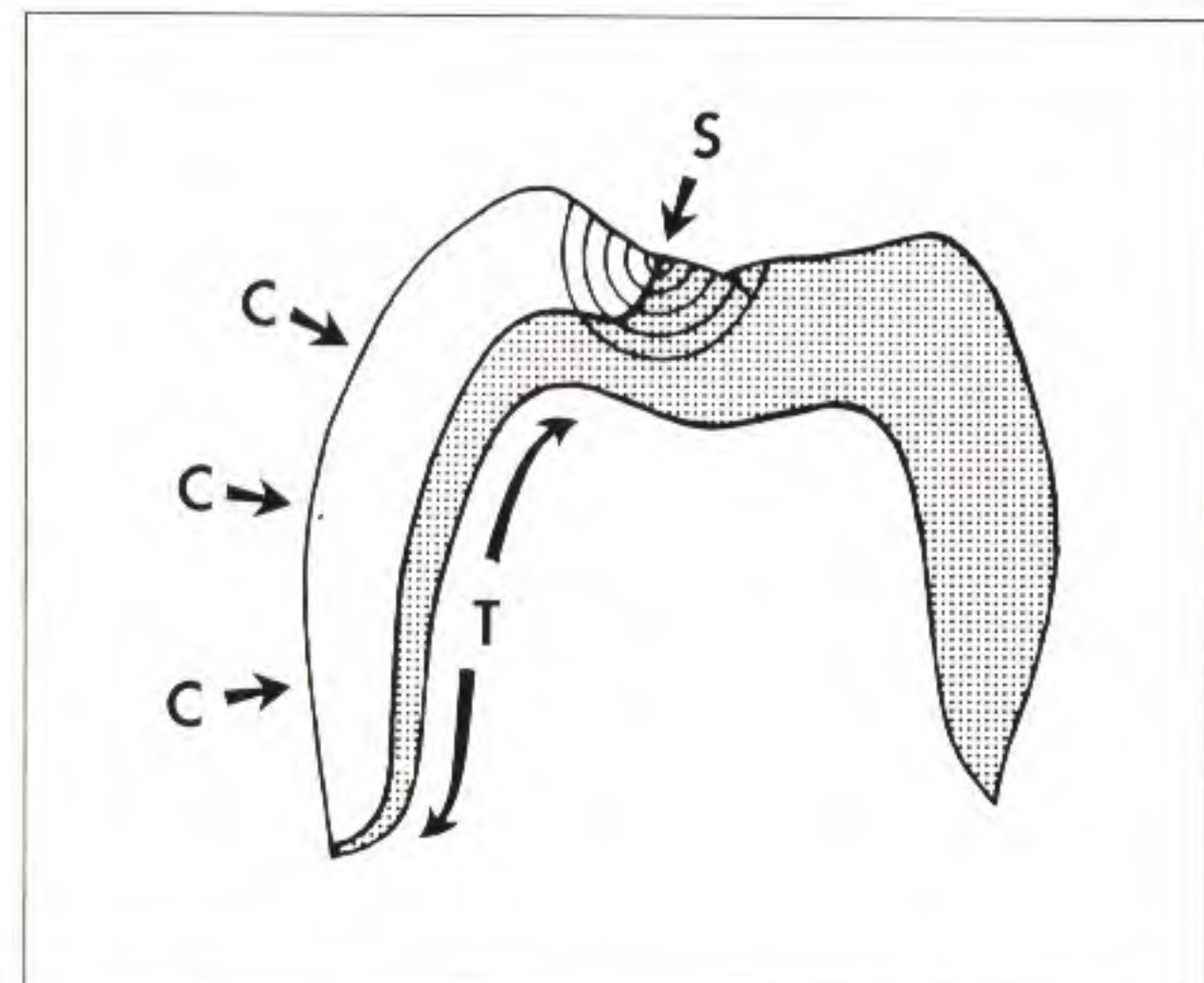


Fig 6-5 Stresses (*S*) at the porcelain-metal junction may arise with a partial porcelain veneer. (*C*) compression; (*T*) tension.

1985). Hence mechanical retention alone is not believed to be sufficient to entirely explain how dental porcelain adheres to a metal substructure.

Compression bonding

Dental porcelain is strongest under compression and weakest under tension; hence, if the coefficient of thermal expansion of the metal substrate is greater than that of the porcelain placed over it, the porcelain should be placed under compression on cooling (McLean, 1980) (Fig 6-4). One point that is not often made is that the theory of compression bonding assumes that the restoration in question is a full-porcelain veneer and not a partial veneer (ie, metal occlusal or lingual) (Figs 6-4 and 6-5). When cooling a restoration with a full-porcelain veneer, the metal contracts faster than the porcelain but is resisted by the porcelain's lower coefficient of thermal expansion. This difference in contraction rates creates tensile forces on the metal and corresponding compressive forces on the porcelain (Figs 6-4 and 6-5). Without the wraparound effect created in a full-porcelain restoration, there is less likelihood this "compression bonding" will develop fully. As a consequence, a partially veneered restoration may not encompass sufficient porcelain-bearing surface to exert significant compressive bonding forces (Fig 6-5).

Despite the stresses that are believed to arise at the porcelain-metal junction, the partial veneer (metal occlusal or lingual) substructure is still regarded as a very successful design, especially for posterior restorations.

Chemical bonding

Most experts agree that the single most significant mechanism of porcelain-metal attachment is a chemical bond between dental porcelain and the oxides on the surface of the metal substructure (Lacy, 1977; McLean, 1980; Murakami and Schulman, 1987).

There are those who believe that two mechanisms might exist within the chemical (or molecular) bonding theory. According to one hypothesis, the oxide layer is permanently bonded to the metal substructure on one side while the dental porcelain remains on the other (Fig 6-6). The oxide layer itself is sandwiched in between the metal substructure and the opaque porcelain. This "sandwich" theory is undesirable in that a thick oxide layer might exist that would weaken the attachment of metal to porcelain. The second, and more likely, theory suggests that the surface oxides dissolve, or are dissolved by, the opaque layer. The porcelain is then brought into atomic contact with the metal surface for enhanced wetting and direct chemical bonding so metal and porcelain share electrons (Fig 6-7) (McLean, 1980; Yamamoto, 1985). From a chemical standpoint, both covalent and ionic bonds are thought to form but only a monomolecular (single) layer of oxides is believed to be required for chemical bonding to occur.

The relationship between the metal surface, oxide layer, and dental porcelain is still somewhat of a mystery. Yet chemical "bonding" is generally accepted as the primary mechanism in the porcelain-metal attachment process (Fig 6-8).

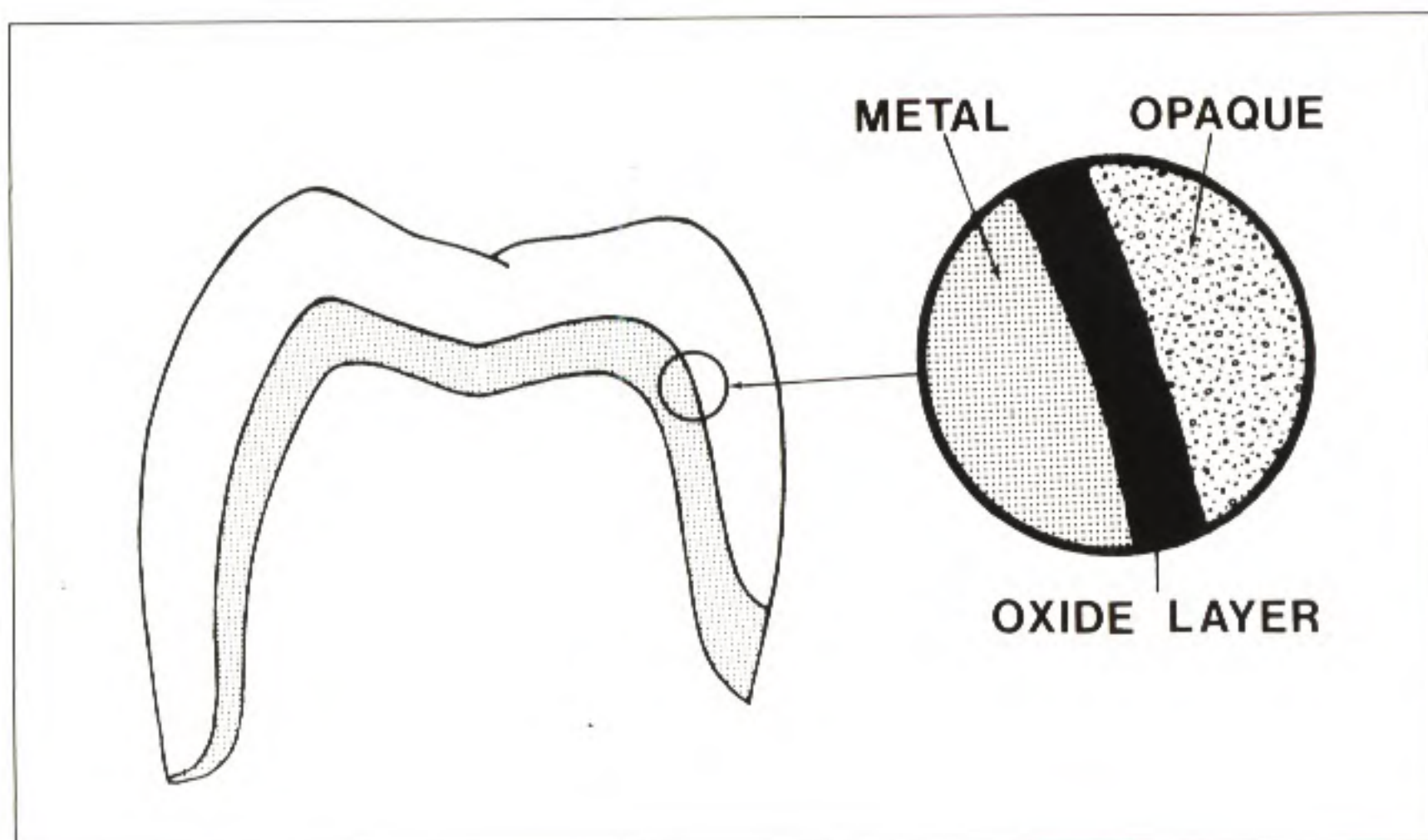


Fig 6-6 On a very basic level, a metal ceramic restoration is made up of a metal substructure, porcelain veneer, and (preferably) an intermediary monomolecular oxide layer.

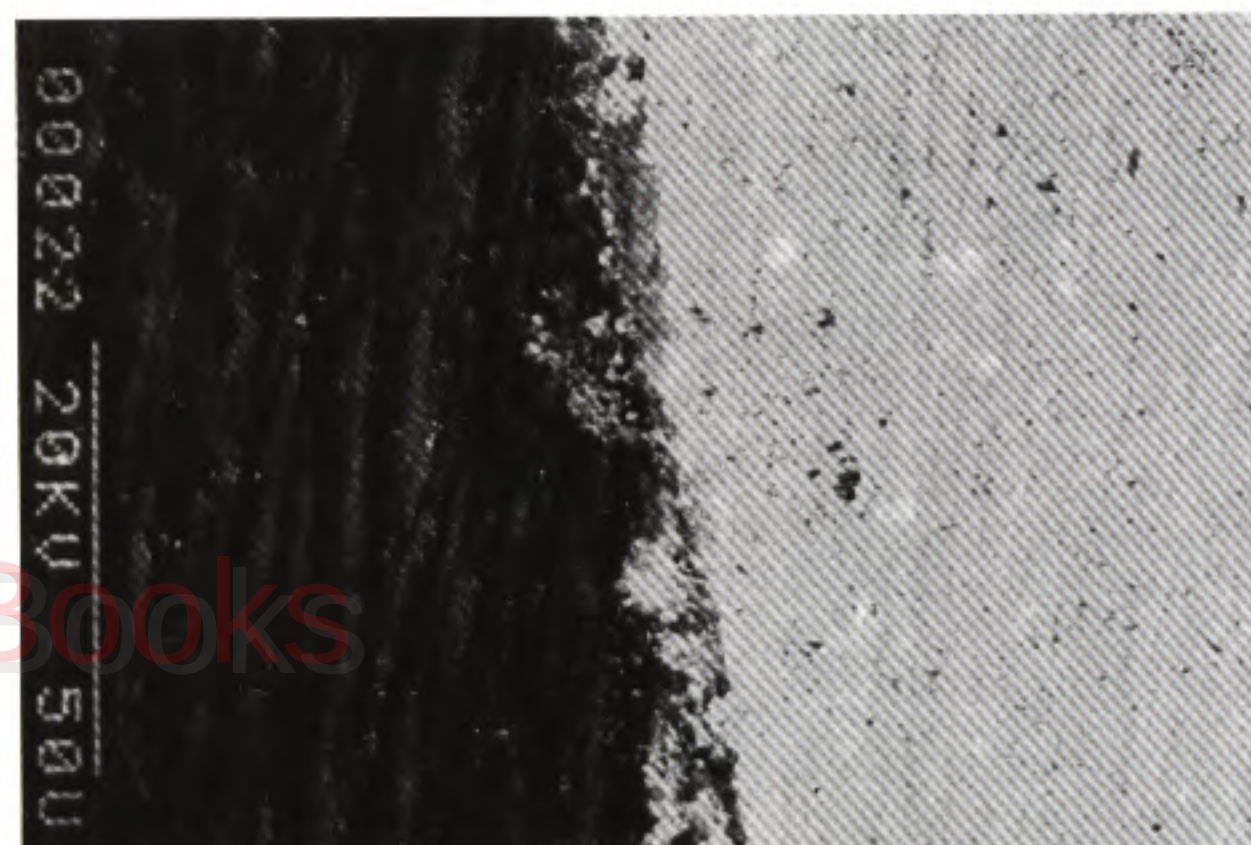
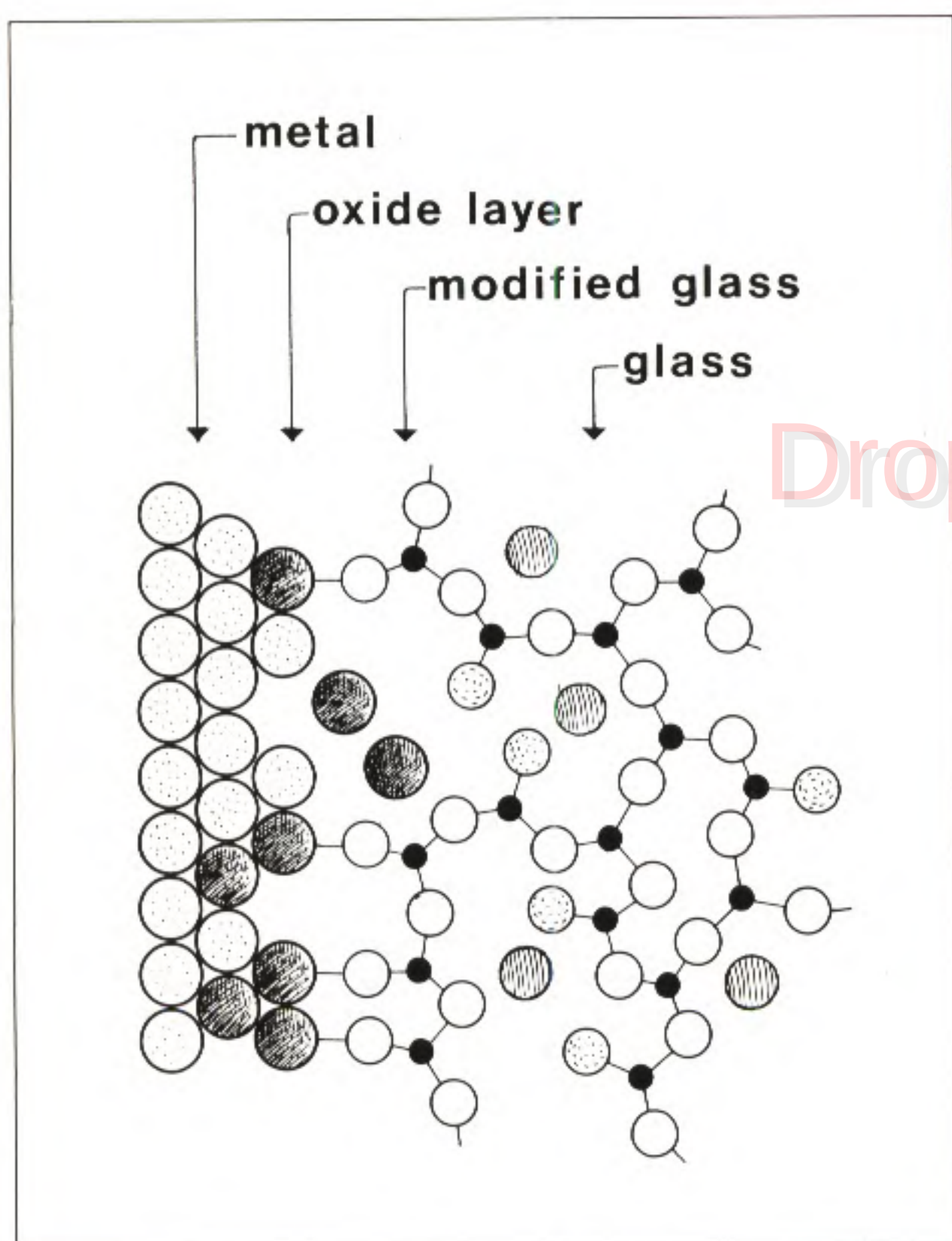


Fig 6-8 The oxide layer of the metal (dark area, left) chemically bonds with the oxides of the opaque porcelain (light area, right) (original magnification $\times 1,000$).

Fig 6-7 The surface oxides produced by the metal substructure chemically bond with the porcelain veneer and produce a zone of modified glass.

The oxidation (degassing) process

One of the principal procedures in the preparation of the metal substructure for porcelain has been described as a degassing or an oxidizing step (McLean, 1980; Naylor, 1986). After the cast metal ceramic castings have been properly finished with uncontami-

nated carbide burs or ceramic abrasives, the work is thoroughly cleaned. Then the castings are heat-treated in a porcelain furnace (in air or a vacuum) to a designated temperature for a specified period of time (Naylor, 1986).

The term *degassing* has been used for a number of



Fig 6-9 All three of these oxidized copings were made with noble alloys, yet their color and character (texture, thickness, etc) differ markedly in appearance. The Olympia casting (*left*) is medium gray and has a moderate level of oxidation. The high palladium-copper alloy (*middle*), Naturelle, has the darkest color (dark brown to black) and the greatest amount of oxidation. The Will-Ceram W-1 casting (a palladium-silver alloy, *right*) is light gray and apparently has a thin oxide layer.



Fig 6-10 The difference in appearance of the oxidized castings is even more distinct when comparing the same high palladium-copper unit (*left*) to a coping made from a palladium-silver (tin only) alloy (*right*). Note that the palladium-silver alloy produces a relatively thin layer of a light gray oxide.



Fig 6-11 These are three different types of base metal alloy (Ni-Cr-Be, *left*; Ni-Cr beryllium free, *middle*; and Co-Cr, *right*). They each form a distinctive colored oxide layer when oxidized.

years to describe a procedure recommended to cleanse the metal of organic debris and remove entrapped surface gases such as hydrogen, hence the term de-gas. High temperature processing like this is vital to the removal of volatile contaminants that might not otherwise be eliminated either by metal finishing, steam cleaning, or air-abrading. Aside from decontamination, the heat-treatment process allows specific oxides to form on the metal surface. These oxides are responsible for the chemical porcelain-metal "bond."

Most recently, the term *oxidation* (oxidizing) has replaced the older designation "degassing" in the dental literature and in many of the written technical instructions accompanying casting alloys (Naylor, 1986; Riley, 1977). The oxidation procedure is actually the same as degassing, the heat treatment of the metal in a porcelain furnace. The major distinction may be in the significance of the procedure itself. The metal substructure is oxidized in the porcelain furnace to form a mature, stable oxide layer for the porcelain-metal attachment (bonding).

Bear in mind that there is no standard oxidizing technique for every alloy on the market. On the contrary, the type of atmosphere (vacuum or air) and the time at temperature will differ among the numerous noble and base metal ceramic alloys (Naylor, 1986). Furthermore, the chemical makeup of the oxides themselves differ among systems because of their particular addition of minor alloying elements. For example, a high-gold-content alloy contains oxidiz-

able trace elements such as tin, indium, and iron to produce an adherent oxide layer. Because elements like gold and the other noble metals do not oxidize, it is often necessary to hold these castings at temperature for several minutes to permit the nonnoble trace elements to form the oxide layer (Figs 6-9 and 6-10). By comparison, the base metal alloys readily oxidize, but trace elements are still added in an effort to form a particular type of oxide for a stable bond (Fig 6-11). The oxidation procedure may be carried out in a vacuum to minimize the amount of oxidation, and the hold time is often reduced or omitted. Allowing certain base metal alloys to oxidize in air, or to remain at temperature, could lead to overoxidation. An excessively thick and non-adherent oxide layer is often responsible for porcelain bond failures (Fig 6-12).

A properly oxidized casting often has a distinctive appearance in terms of color and character (texture, thickness, etc). That appearance of a properly oxidized metal substructure differs among alloy systems and may also differ among alloys within the same system (see Fig 6-11). Variations outside expected results should be reassessed and, perhaps, discussed with the alloy manufacturer. Bear in mind that some manufacturers do not recommend an oxidation/degassing step; instead, they advocate minimizing the number of firings to which the casting is subjected. They contend oxidation heat-softens certain types of alloys through molecular rearrangement, which results in marginal distortion and a decrease in bond strength (Stein and Kuwata, 1977).



Fig 6-12 Porcelain-metal bond failures can occur through the oxide layer itself, if it is too thick or poorly adherent. Note how the ideal strawlike color of the oxide layer remains bonded to the porcelain and cleanly separates from the metal surface.

These potential limitations aside, the majority of alloy manufacturers consider the oxidation process a necessary step in the fabrication of the metal ceramic restoration.

To avoid any possible mistakes, follow the manufacturer's instructions as closely as possible and do not apply general, broad processing information to every alloy. But remember, you will have to adjust the manufacturer's oxidation firing cycle to accommodate the firing characteristics of your particular porcelain furnace. The recommended firing temperatures are only general guidelines that should be adjusted to the unique demands of each type (horizontal muffle versus vertical muffle) and brand of furnace.

Postoxidation treatment

Recommendations for the postoxidation treatment also vary for different types and brands of alloy. With some metals it is best not to remove the oxide layer but to proceed directly to the application of opaque porcelain. The first oxides formed may be the most desirable for porcelain bonding, as seen with several of the noble and base metals (Naylor, 1986). For other types of alloys, manufacturers suggest air-abrading or acid treating the casting to reduce the oxide layer or remove surface contaminants. Despite these procedures, the casting still retains a monomolecular layer of oxides for porcelain-metal bonding. Air-abrading only minimizes the thickness of oxides and rids the surface of unseen debris. Of course, any blasting should be followed by steam cleaning or a 5- to 10-minute cleansing in distilled water using an ultrasonic unit. In some instances, the alloy manufac-

turer may not indicate a preference either for retaining the oxide layer or removing it. That choice, along with the decision of how to remove the oxides, is left to the dental technician.

Removing the oxide layer

Two principal methods for removing oxides are acid treatment (chemical method) or nonacid treatment (mechanical method).

Acid treatment (chemical method)

A number of different types of acids are used to reduce or eliminate surface oxides, including hydrofluoric, hydrochloric, and dilute sulfuric acid (Sarkar et al, 1985; Yamamoto, 1985). The potential hazards of these acids require that they be stored and used in clearly marked, resealable plastics bottles. For added safety, these containers should be maintained in a hooded area in the laboratory. It is advisable to wear protective rubber gloves and eye protection during all handling procedures. Use a rubber-tipped instrument to place oxidized castings into the acid appropriate for the alloy. Place the covered container in an ultrasonic unit for the time recommended by the alloy manufacturer. Remove the casting and thoroughly rinse it under tap water. For the final cleaning step, put the coping in a container of distilled water and clean it ultrasonically for 10 to 15 minutes.

Expect the type of acid, and even the recommendation to use acids, to vary with the different alloy systems and manufacturers. To lessen the risk of injury associated with potential mishandling of acids, some users of acid treatments prefer a hydrofluoric acid (HF) substitute such as NoSan (Trio-Dent, Inc).



Fig 6-13a This type of bond failure is often referred to as a loss of "attachment" or a "delamination" of the porcelain from the metal substructure.

Nonacid treatment (mechanical method)

Not everyone is eager to handle acids on a routine basis when a mechanical method of oxide removal also is available. Castings can be air-abraded with pure, 50- μ m aluminum oxide (Al_2O_3) that is non-recycled. The aluminum oxide should not be reused because it might contaminate the porcelain-bearing surface of the metal (see Fig 5-23 in chapter 5). Steam clean or ultrasonically clean the casting in distilled water for 10 to 15 minutes before applying the opaque porcelain.

Traditionally, sand has been used for "blasting" complete gold crowns to remove investment residue. The term sandblasting has carried over into the metal ceramic terminology, but it is perhaps more correct to describe the procedure as *air-abrading*.

The cost of purchasing an air-abrasion unit or buying the components separately and constructing your own unit is well worth the expenditure. Direct contact of hydrofluoric acid with the skin can cause very serious injury and requires immediate medical attention (Wilson et al, 1979).

Porcelain-metal bond failures

Metal ceramic alloys, whether noble or base metals, all oxidize differently because of variations in their composition. If the oxidation process is not performed properly, the subsequent porcelain-metal bond may be weak. The consequences of bond failure, be the failure immediate or delayed, obviously are costly.

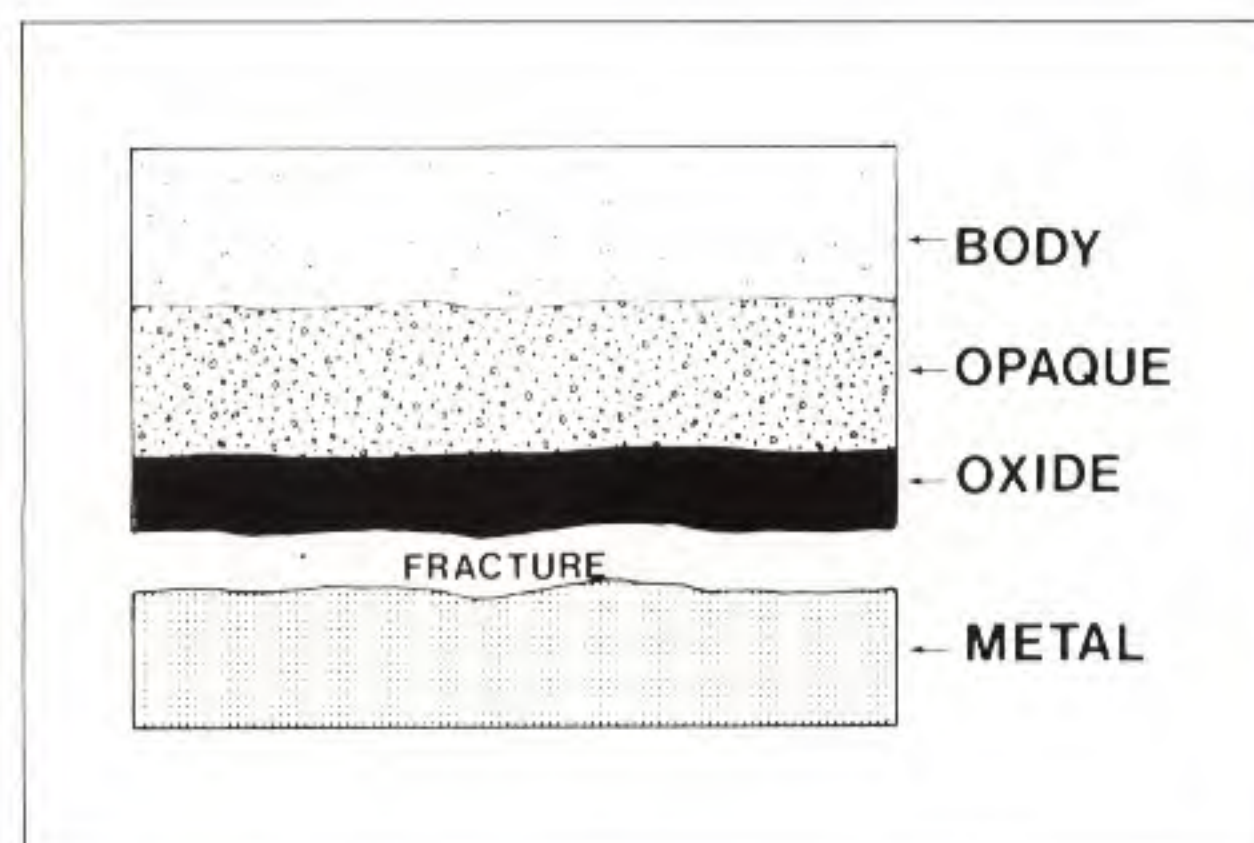


Fig 6-13b The complete detachment from the metal by the dental porcelain may be caused by excessive oxide formation or a poorly adherent oxide layer.

Porcelain delamination

With base metal alloys, the separation of the porcelain veneer from the metal substrate can be more a loss of the "attachment" of the oxide layer that is either too thick or is poorly adherent to the metal substructure (Mackert et al, 1981). The porcelain and oxide film retain their bond yet become detached or delaminated at the porcelain-metal junction (Figs 6-13a and b). Overoxidation has been a particular problem with the heavily oxidizing base metal alloys and has been linked to their increased tendency for bond failures. In some instances, bond failures are not caused by a loss of the chemical bond between the ceramic and the oxide layer; on the contrary, the porcelain might remain visibly attached to the oxides but the oxide layer may be so thick that the bond is lost through it (Figs 6-14a and b). This particular problem is caused by the formation of a thick and poorly adherent oxide layer.

Likewise, excessive absorption of oxides by the porcelain can lower the porcelain's coefficient of thermal expansion, alter the final shade (cause a graying or bluing), or do both (Naylor, 1986) (Fig 6-15). Changes in the shade of the porcelain may not be noticeable with posterior restorations, particularly if a greater thickness of porcelain masks the dark oxides (Fig 6-16). Such shade changes can occur with noble metal alloys (Naylor, 1986). What is more, the oxide masking ability of opaques is not the same for all brands of dental porcelains (Wilson et al, 1979).

Incompatible materials

Futhermore, bond failures are not always attributable to improper oxidation but may actually be caused by a



Fig 6-14a Note how the heavy greenish oxides bonded to the porcelain (*left*) yet a substantial amount of oxidation remains on the metal substructure (*right*) of this cobalt-chromium casting.

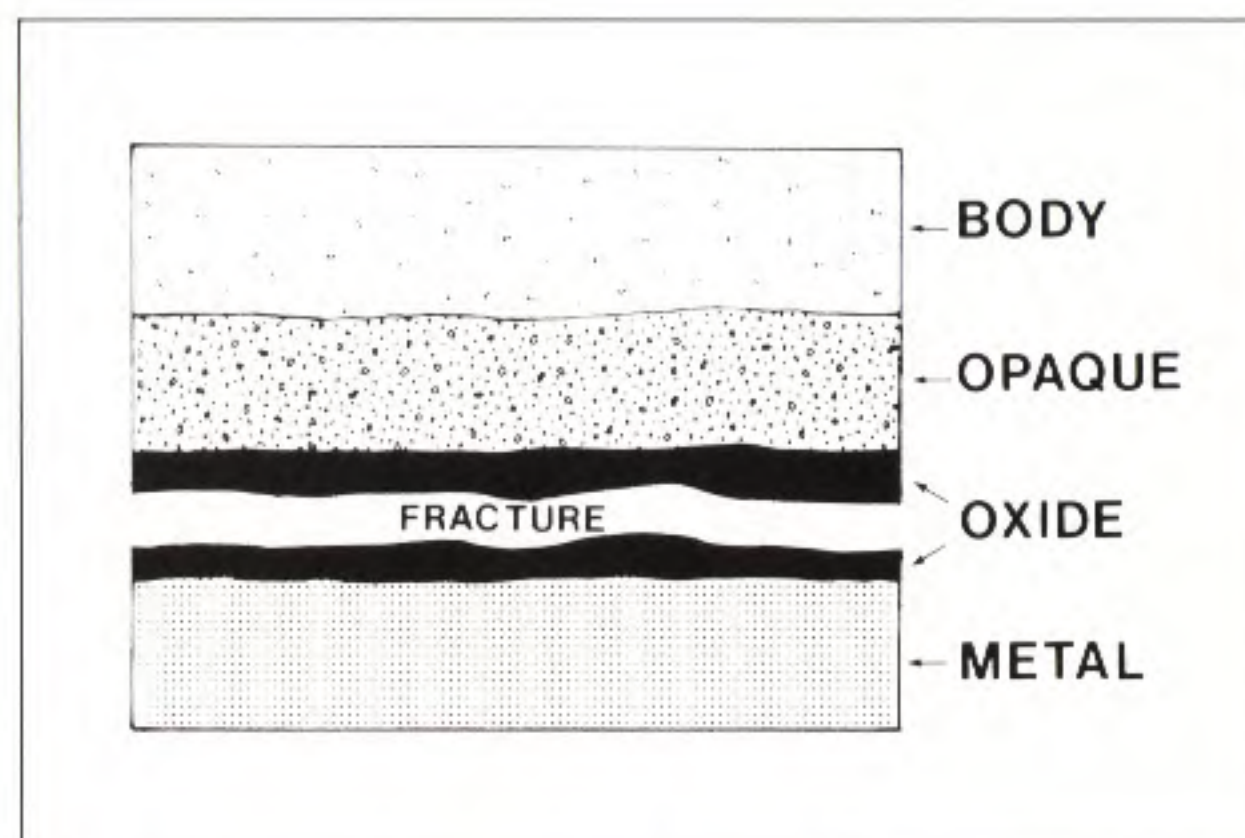


Fig 6-14b The bond failure occurred through the thick oxide layer, leaving oxidation on both porcelain and metal.



Fig 6-15 Graying of the dental porcelain may occur if the opaque porcelain cannot mask the metal and control the dark oxides that the alloy produces. The metal ceramic restoration on the maxillary right central incisor was fabricated with a high palladium-copper alloy. Note the very distinctive graying of the porcelain. This crown must be remade, because such a color change cannot be corrected with surface stains.



Fig 6-16 The placement of another brand of dental porcelain (Will-Ceram) on a different high palladium-copper alloy did not result in any discoloration of the porcelain on the metal ceramic crown seen on the maxillary right first molar. Perhaps the greater thickness of porcelain or a fewer number of body bakes prevented the discoloration from occurring.



Fig 6-17 The cracking of the porcelain on the base metal alloy unit (*left*) is an indication of a possible porcelain-metal incompatibility, which could lead to either an immediate or a delayed bond failure (*right*).

physical incompatibility between the porcelain and the metal substructure. The difference in the coefficient of thermal expansion of the veneering porcelain and the metal ceramic alloy may be slight yet sufficient to be responsible for cracking of the ceramic veneer (Fig 6-17, *left*) or substantial enough to result in porcelain debonding (Fig 6-17, *right*).

Overoxidation/underoxidation

The oxidation procedure varies for alloys of different compositions, so the process itself should not be taken for granted. No one technique can be used for every type of metal ceramic alloy. Careful processing followed by an assessment of the postoxidation ap-



Fig 6-18a (left) Although the manufacturer's directions were followed, bubbling of the opaque porcelain occurred on this high palladium-copper alloy.

Fig 6-18b (right) Removing the opaque bubbles revealed areas where the porcelain did not bond or where it debonded during the opaque firing cycle.

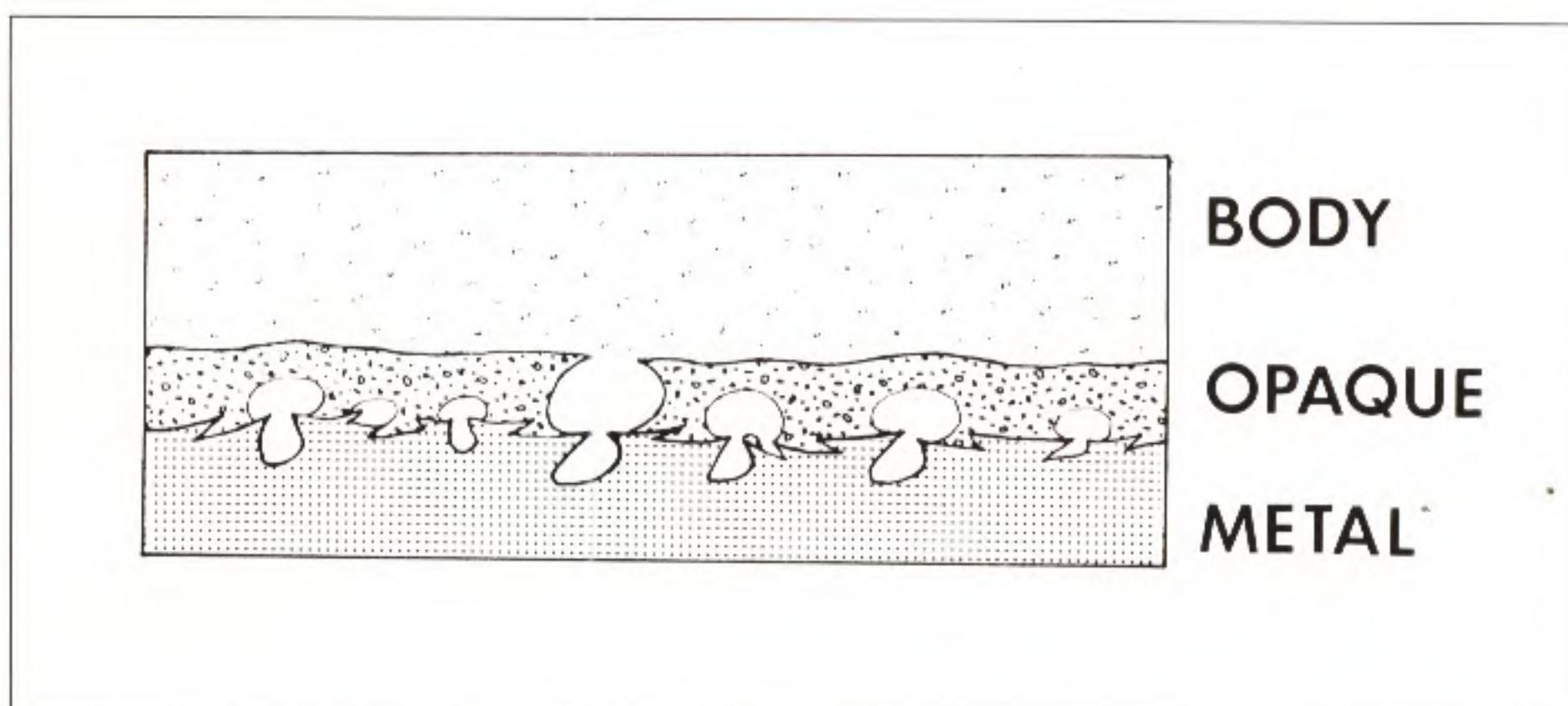


Fig 6-18c Surface or subsurface contaminants produce the bubble formation during firing of the porcelain.



Fig 6-18d Simply refinishing this casting removed the surface and subsurface contamination and resulted in an appropriate porcelain-metal bond.

pearance of each casting will ensure that the procedure was accomplished correctly. Castings that are either overoxidized or underoxidized should be reprocessed accordingly until a uniform oxide of the desired color and thickness recommended for the alloy involved has formed.

Contamination

Very often castings that demonstrate some form of contamination may not have to be remade. In some instances, simply refinishing a substructure's porcelain-bearing surface may be all that is necessary when surface debonding becomes evident (Figs 6-18a to d). One assumption being made in this recommendation is that the level of contamination is not extensive. In these situations the best results are often obtained by making certain that only clean,

uncontaminated finishing materials are used. For added safety, dedicate a set of finishing abrasives for each particular type of alloy being resurfaced to avoid cross-contamination.

Summary

The porcelain-metal bond undoubtedly is established through a variety of complex processes, and our understanding of the bonding mechanisms involved continues to grow. This chapter was intended to provide an explanation of the theories behind that bonding process, how to optimize that bond, and how to identify different types of bond failures. In chapter 7 you will learn how to prepare the metal substructure for dental porcelain through proper adjusting, finishing, and oxidation techniques.

Preparation of the Metal Substructure for Porcelain

Introduction

If you were very meticulous in the waxup stage, preparation of the metal substructure should proceed quickly. However, if you hastily constructed or poorly designed the waxup, you may need more time for the adjusting and finishing procedures than is usually necessary. Metal preparation is possibly the last opportunity you will have to correct any minor substructure design deficiencies, so it is especially helpful if you are familiar with the principles of proper substructure design (see chapter 4).

Casting appraisal

At this point, take the time to closely inspect the casting for any deficiencies that may have resulted from the casting process; a microscope or other form of magnification is recommended (Fig 7-1). Examine the casting carefully to make certain it is dense and the casting porosity is not located in the restoration itself (Fig 7-2a). Check the margins to make certain they are complete and sharp; also, be sure to inspect the restoration for the presence of nodules or excessive surface roughness (Fig 7-2b).

If there are discrepancies, make note of them now in order to prevent a recurrence in subsequent cases. If the casting is judged to be inadequate, do not begin finishing the metal substructure for porcelain; you run the risk of damaging the master die and wasting a great deal of time. Simply reject the casting and re wax the case. Assuming the restoration is satisfactory, however, you are now ready to begin the adjusting and finishing process.

Armamentarium

It is common to think that you must surround yourself

with a large assortment of equipment and materials even to perform some very simple tasks. On the contrary, once you possess an understanding of what is involved with metal finishing and have mastered a technique, you will find that very few items are actually required for the procedures you must perform.

The armamentarium for adjusting and finishing the metal substructure can best be divided into three categories: equipment, instruments, and materials (see Appendix E).

Equipment

One of the most valuable tools in the laboratory is the microscope. A laboratory microscope can be used for a multitude of procedures such as waxing margins, fitting and adjusting metal substructures, and adjusting and finishing the final restoration. The popularity of using some means of magnification in dental technology has led to the development of a variety of equipment. In fact, there are many different types and styles of microscopes to choose from (Figs 7-3a to c). For most laboratory procedures, a magnification level between $\times 7$ and $\times 20$ is adequate. Should you need to purchase a microscope, find one that comes with a good external light source and has an adequate working distance under the tube head. A design that permits mounting above the bench top leaves the immediate work area free of clutter. Such a design not only makes it easier for you to function, it also helps to reduce the instruments' level of exposure to debris generated by grinding and polishing procedures. However, the selection of a microscope should be based on the overall quality of the unit, not merely how it is mounted.

Virtually any type of handpiece or bench-top lathe will be adequate for the metal finishing procedures. Generally, a hand engine with speeds below 50,000 rpm is preferred. This type of handpiece accepts most commonly used abrasives (stones, diamond instruments, carbide burs, mandrels for disks, etc) and



Fig 7-1 Inspect the inside of castings with the aid of some form of magnification.



Fig 7-2a The completed casting should be dense and smooth. Note the smooth transition from the sprue to the restoration.

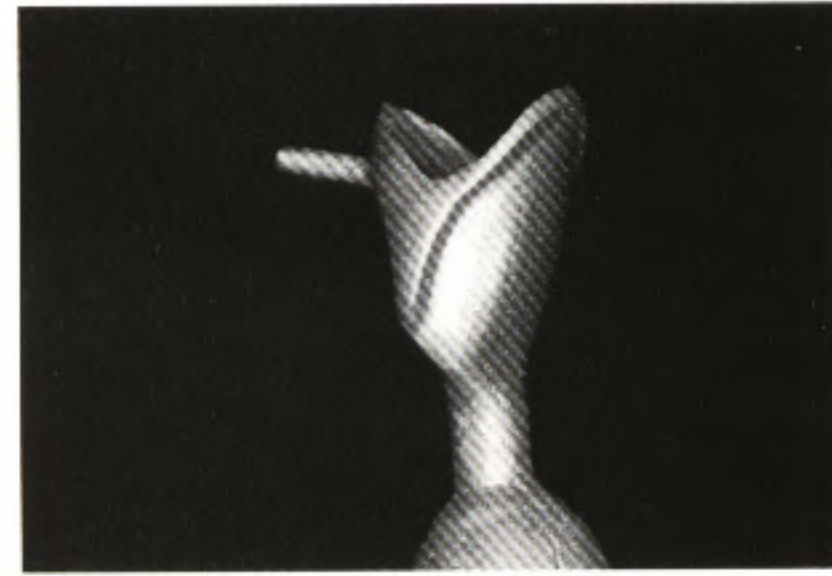


Fig 7-2b The margins of the casting should be complete and sharp.

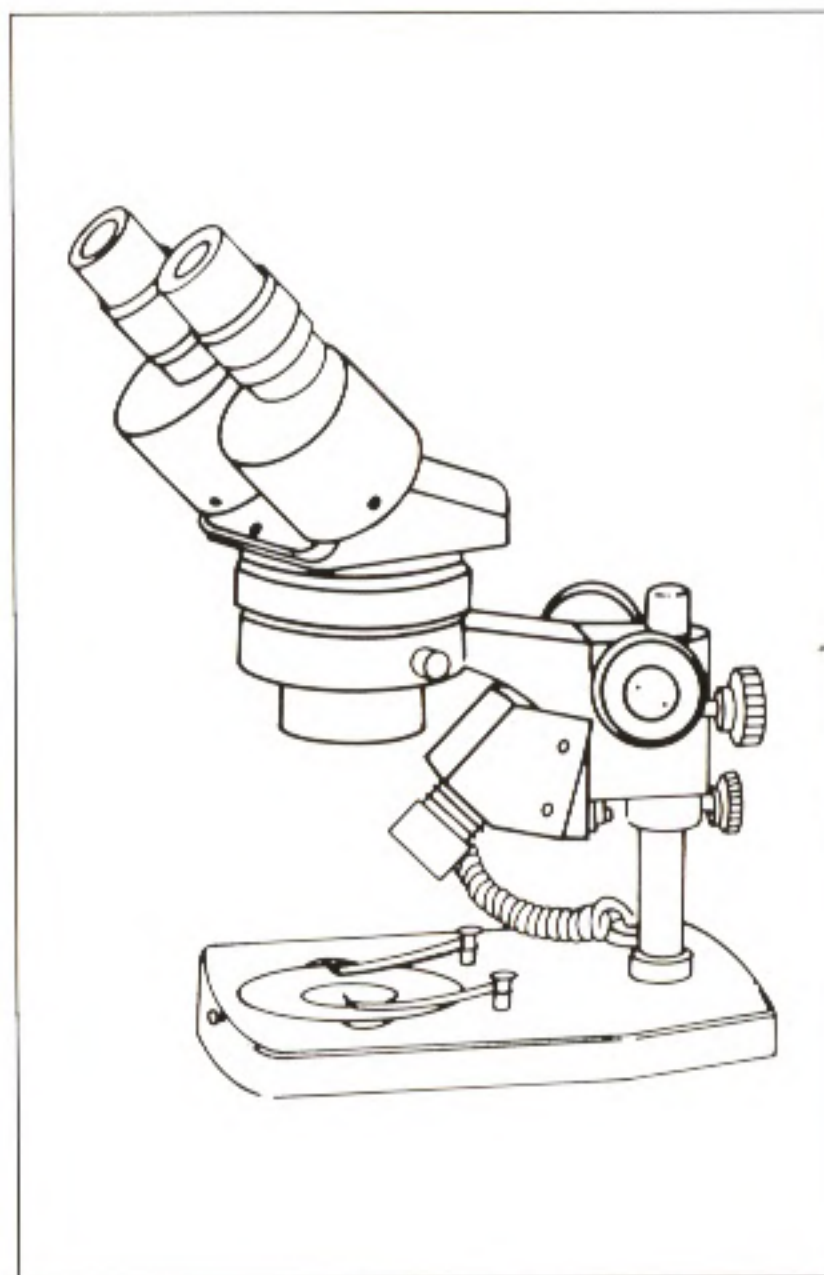
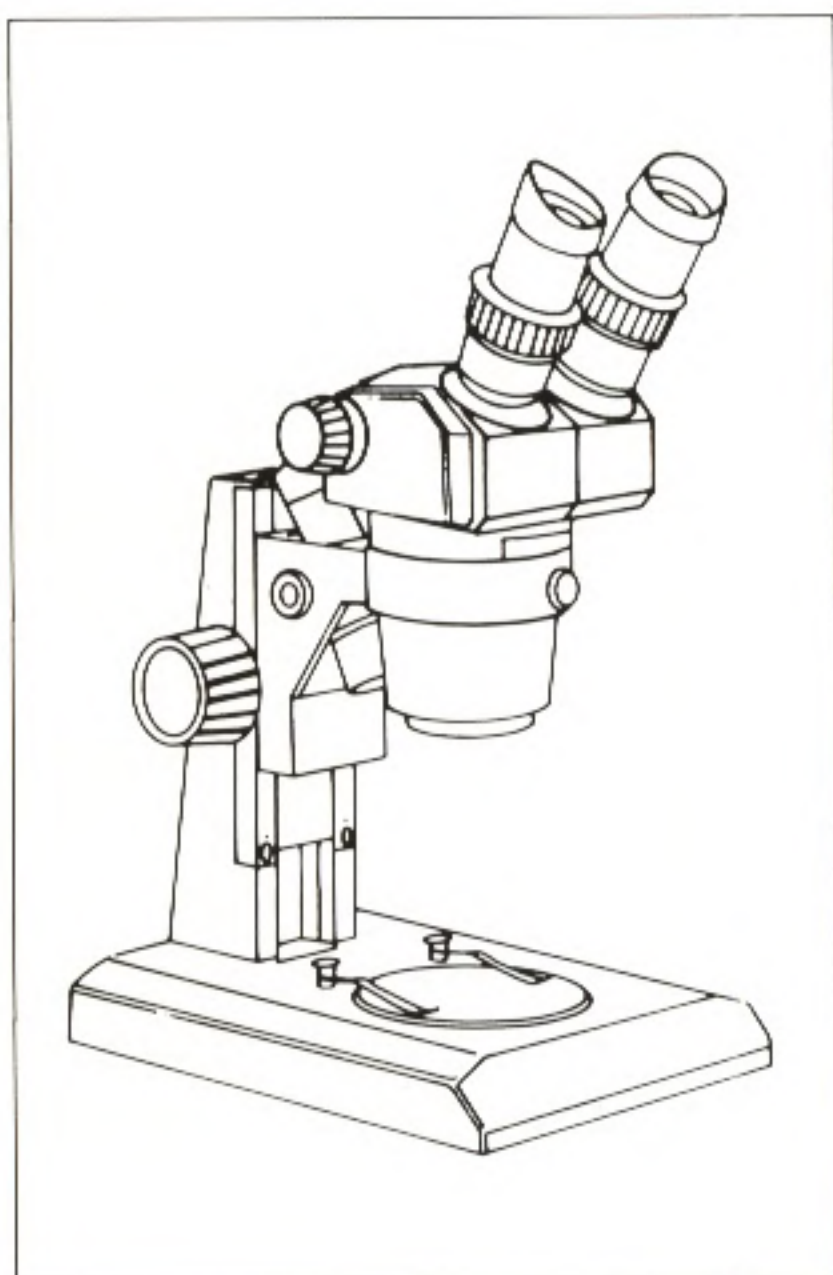


Fig 7-3a (left) The Nikon SMZ-1 stereomicroscope.

Fig 7-3b (right) The Meiji EMZ-2 stereomicroscope with ring fluorescent illuminator.

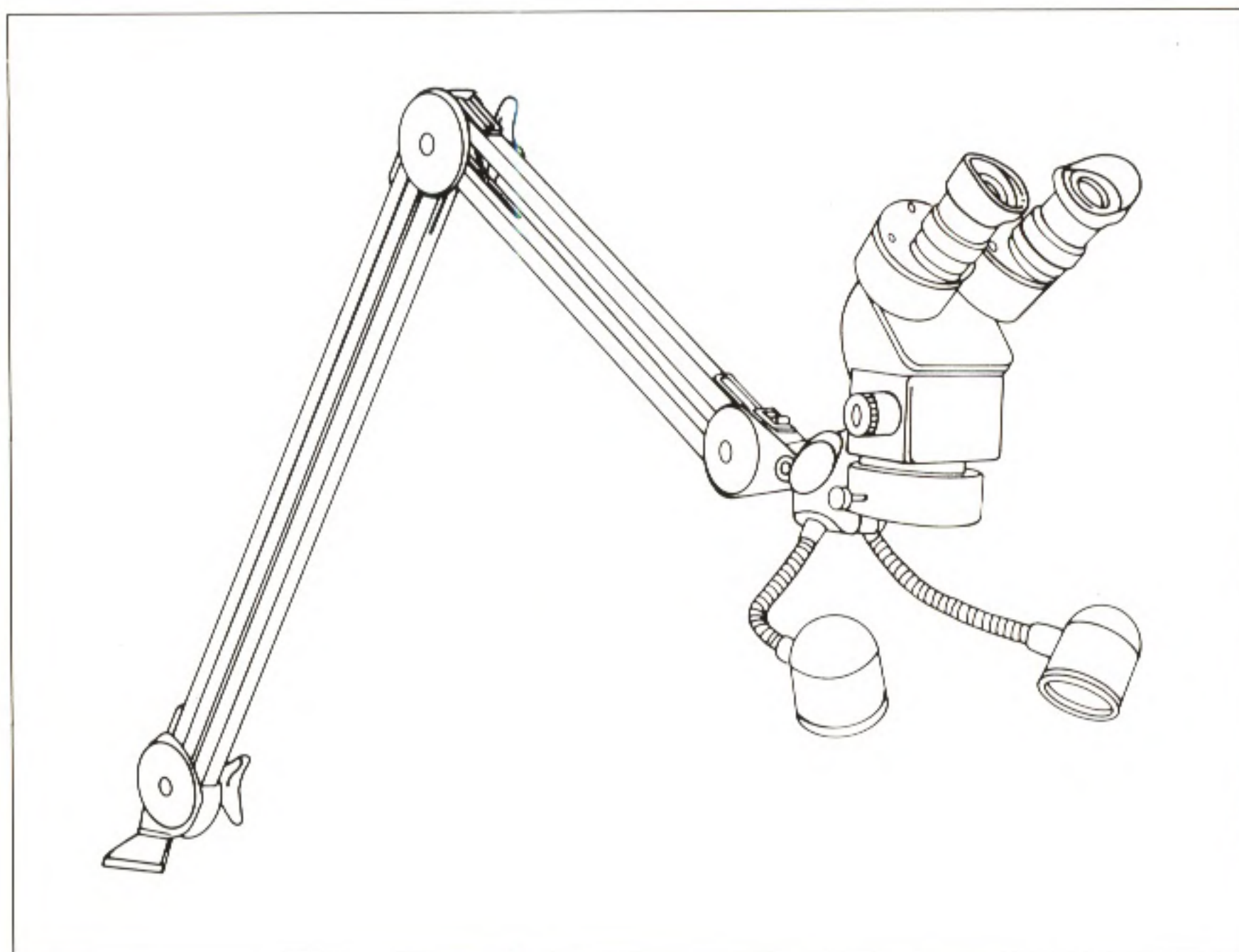


Fig 7-3c The Denerica KRX stereomicroscope with swing arm and table clamp.

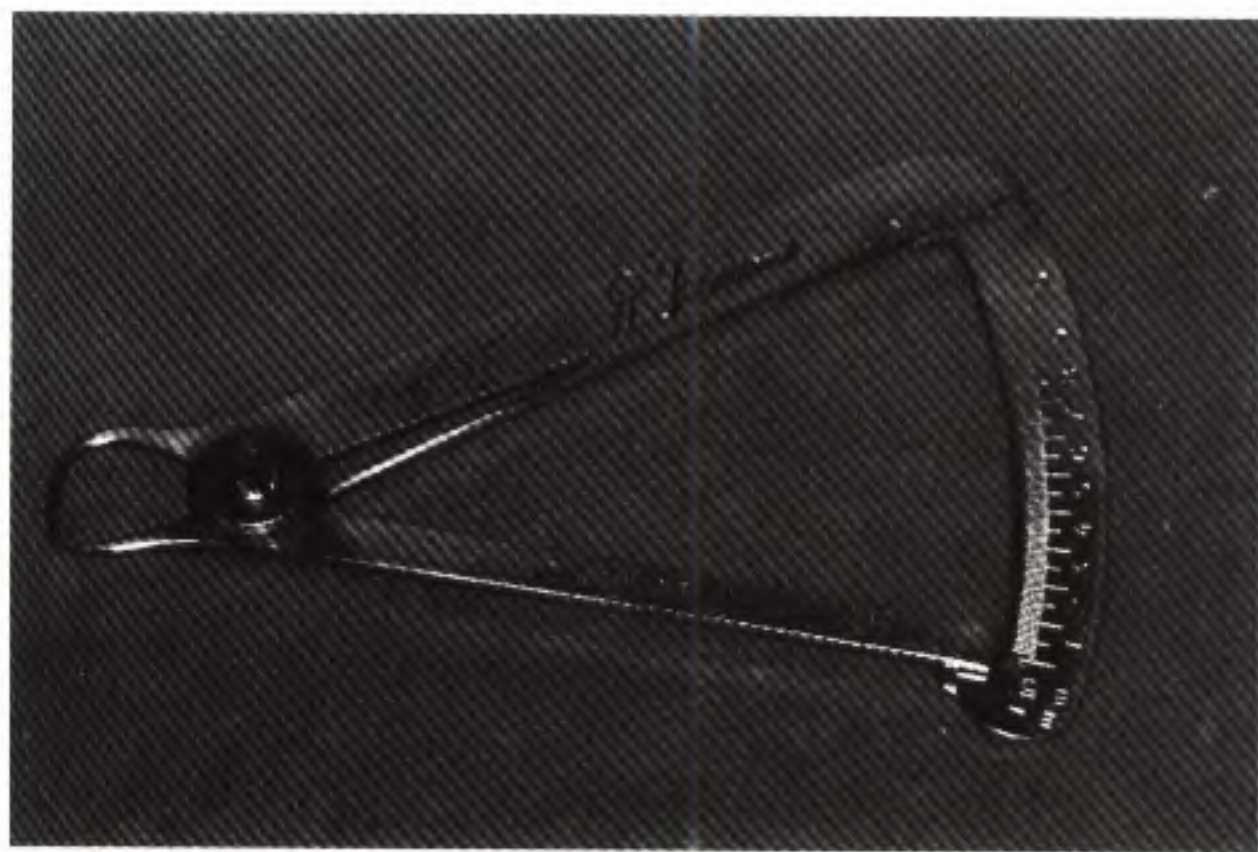


Fig 7-4 A measuring caliper for metal (Pfingst Co). The caliper tips for measuring metal thickness have flat ends and a small diameter.



Fig 7-5 Assorted ceramic stones for metal finishing.



Fig 7-6 Assorted round carbide burs: no. 1/2 (*left*), no. 2 (*middle*), and no. 8 (*right*) used for fitting and adjusting.



Fig 7-7 Assorted carbide burs for adjusting and finishing the porcelain-bearing areas of a metal substructure (Brasseler USA, Inc). Note the varied shapes and designs.

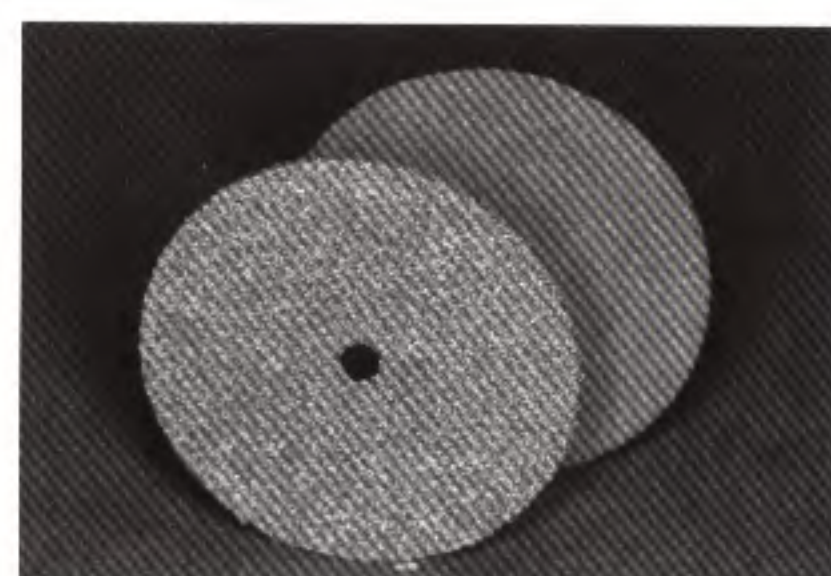


Fig 7-8 Coarse (*foreground*) and fine (*background*) carborundum disks.

rotates at speeds that are less likely to damage the cast restoration (see Appendix E).

Instruments

Only one instrument is absolutely necessary for the metal finishing procedures, and that is a metal caliper (Fig 7-4; see Appendix E). You will use this gauge throughout all the adjusting and finishing stages to measure the thickness of the remaining metal substructure in both the porcelain-bearing and the nonporcelain-bearing areas.

Materials

A wide assortment of materials is available for metal finishing (Figs 7-5 to 7-8). This is due, in part, to the fact that you need to perform such a variety of tasks, from

removing the sprue to recontouring the coping, finishing the porcelain-bearing surfaces, and eventually smoothing the nonporcelain-bearing regions.

Care should be taken when selecting the composition of abrasives, because certain types can actually contaminate the metal surface and jeopardize the porcelain-metal bond. Debris from some abrasives (or from the abrasive binder) that remains on the surface of the porcelain-bearing areas can release gas when the restoration is heated (Yamamoto, 1985). These gaseous by-products, which are capable of expanding to 80 times their original volume, can cause bubbling of the opaque porcelain or prevent an adherent porcelain-metal bond (Yamamoto, 1985).

To avoid any potential problems with surface contamination, use a ceramic abrasive (see Fig 7-5) or a carbide bur (see Figs 7-6 and 7-7) for metal preparation whenever possible (see Appendix E). At the very minimum, these abrasives should be used for the final stages of surface preparation.

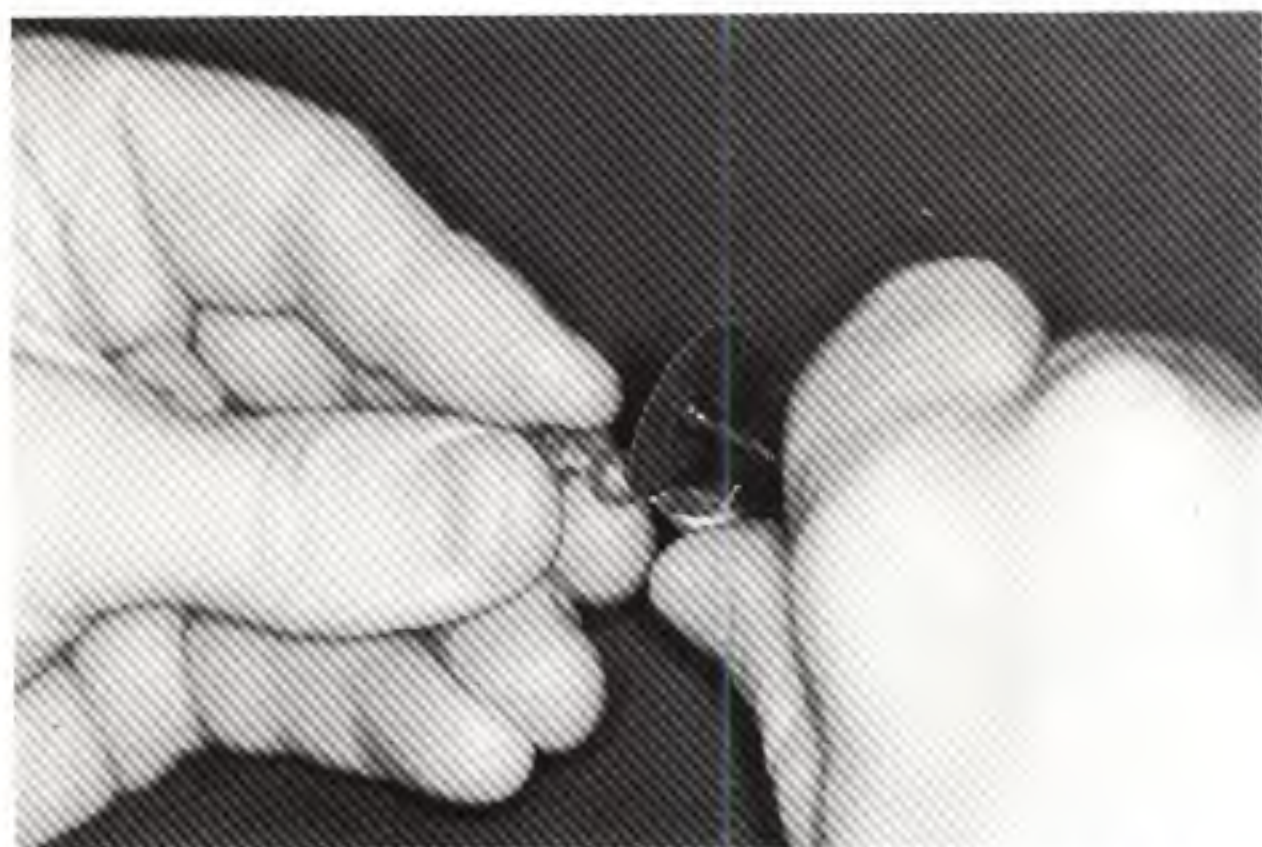


Fig 7-9 Using a strong thumb grip on the handpiece, make a cut in the sprue on the facial surface as close to the restoration as possible. Rotate the casting 180 degrees and place a second cut on the lingual aspect of the sprue.



Fig 7-10 With two cuts on opposite sides of one another, the restoration is alternately moved facially and lingually until the crown separates from the sprue.

Metal finishing procedures

Before you begin any metal finishing, make certain all residual investment has been removed from the casting. Quite frequently debris will remain hidden inside a restoration in a corner or will possibly cling to the occlusal or lingual surfaces. For that matter, do not forget to thoroughly clean the sprues that remain before you store any spent alloy. If the metal is to be recast, investment remaining on a sprue may end up in the next casting and cause pitting or even a miscast margin.

As with most laboratory procedures, metal finishing should be accomplished in an orderly fashion. The basic idea is to finish the metal through a series of sequential steps, beginning with coarse abrasives and gradually working your way to a final finish with fine abrasives.

Removing the sprue (de-spruing)

After you have inspected the casting and found it satisfactory, the first procedure you will perform in the adjusting and finishing process is to remove the sprue(s) from the completed casting. Many technicians prefer to use a bench-top lathe for de-spruing because it is generally quicker and safer. Others prefer the convenience and control of a slow-speed handpiece. In addition to your selection of cutting equipment, you may choose between a thin or a thick carborundum disk mounted on a mandrel (see Fig 7-8). Although the thicker disks generate more heat, produce additional dust, and remove excessive amounts of alloy, they are also less likely to break

during cutting. While holding the restoration securely in one hand, carefully remove the sprues, cutting as close as possible to the restoration (Fig 7-9). If you are uncertain about how close you should make the cut, err on the safe side and leave some additional sprue length on the restoration. That area can always be adjusted later. While you are cutting, be extremely careful not to damage any of the other restorations that may be connected to the same sprue system. Because this is such an important step, avoid distractions while de-spruing, especially if you are using a lathe. As an added safety measure, turn on the high-speed evacuation system to the lathe, adjust the lathe's plastic shield to protect yourself, and wear safety glasses. It is not necessary to cut completely through the diameter of the cast sprue. After making a cut on one side, rotate the casting and make a similar cut on the opposite side (Fig 7-9). At this point you should be able to move the casting back and forth until it simply detaches from the sprue (Fig 7-10).

Fitting the cast restoration

Once the restoration is de-sprued, you should always fit it to its die before you remove remnants of the sprues, begin any surface finishing procedures, or further reduce the facial surface. In this way you will ensure, at the earliest possible time, that the fit is satisfactory and the margins are acceptable. If the inside of the restoration requires extensive adjustment, you will minimize the possibility of perforating the metal substructure.

In most cases, the master cast with removable dies



Fig 7-11 With the aid of a microscope, remove any internal nodules or defects that would prevent the complete seat of the casting or abrade the gypsum die. A no. 1/2 round carbide bur is ideal for removing small nodules and making minor adjustments on the inside of castings.



Fig 7-12a Occlude (Pascal) sprayed into the inside of a casting.



Fig 7-12b A casting after being sprayed with Occlude has a thin, uniform layer of the disclosing medium.

is your only indication of the prepared tooth or teeth; therefore, take every precaution not to damage it. One small chip of the gypsum margin during metal finishing may necessitate extensive chairside adjustment by the dentist or result in a clinically unacceptable restoration. Whenever possible, immediately repour the final impression to obtain a second die on which to seat the work. This relatively inexpensive and quick procedure can save you a great deal of time and help ensure an accurate and well-fitting final restoration.

From your initial inspection of the inside of the casting you may have already identified any obvious nodules or irregularities (Fig 7-11). With the aid of a microscope, use a small no. 1/2 round carbide bur to remove small nodules (see Fig 7-6, left).

Next, use a disclosing medium to fit the restoration to the die. There are a number of commercial products on the market designed for this type of application, for instance, aerosol spray indicators such as Occlude (Pascal Co) and paint-on liquid such as Crown Fit Seating Indicator (Belle de St Claire) and AccuFilm IV (Parkell). There are two ways to use disclosing agents: disclose the die or disclose the restoration. Both techniques work well; however, when disclosing media are sprayed into or brushed onto the inside of a casting (Figs 7-12 and 7-13), the medium can build up internally with repeated applications. Depending on the extent of the adjustment

needed, periodic cleaning of the restoration may be necessary.

It is easier, neater, and probably less time-consuming to coat your second die with a very thin layer of disclosing material (Figs 7-14 and 7-15) and gently seat the restoration on the die (Fig 7-16). Remove the restoration from the die and inspect the internal surface of the casting where necessary (Fig 7-17). Also, examine the die itself for evidence of contact that may not have transferred to the casting (Fig 7-18). Use a small round carbide bur to make any necessary adjustments (Fig 7-19). Repeat the process until the restoration is completely seated (Fig 7-20). If the fit of the restoration is less than perfect (eg, is over- or underexpanded), make note so changes can be made in your investing technique for future cases. If all the previous procedures were performed correctly, the restoration should seat completely on the master die. Assuming the fit is satisfactory, return the casting to the master die.

Recontouring the sprue area

With the fit of the restoration confirmed, carefully reduce the areas where remnants of sprues remain, using a coarse ceramic abrasive such as a heatless stone (Mizzy, Inc; Fig 7-21). This area must be adjusted so the casting can be returned to the mounted



Fig 7-13 The liquid Crown Fit (Belle de St Claire) must be applied to the inside of a casting with the attached brush.

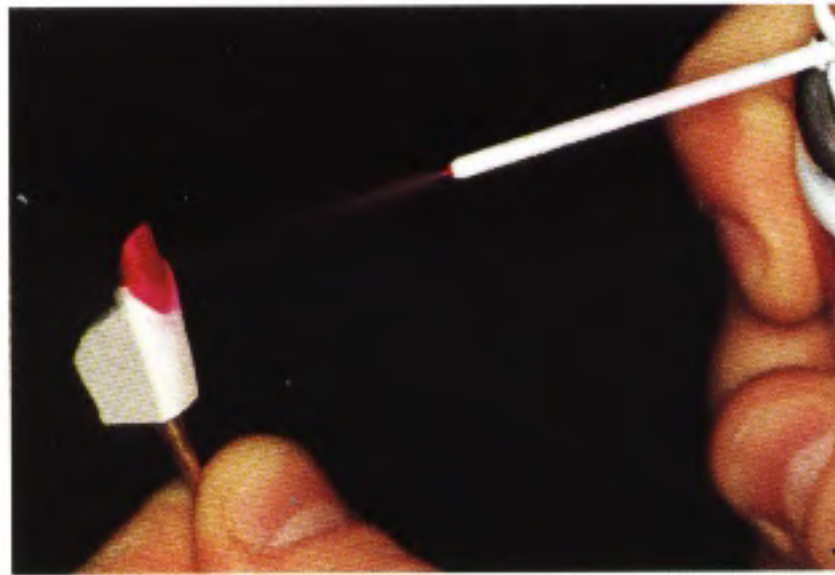


Fig 7-14a Occlude aerosol sprayed onto the gypsum die (secondary die, if possible).



Fig 7-14b Gypsum die sprayed with Occlude and ready to receive castings.

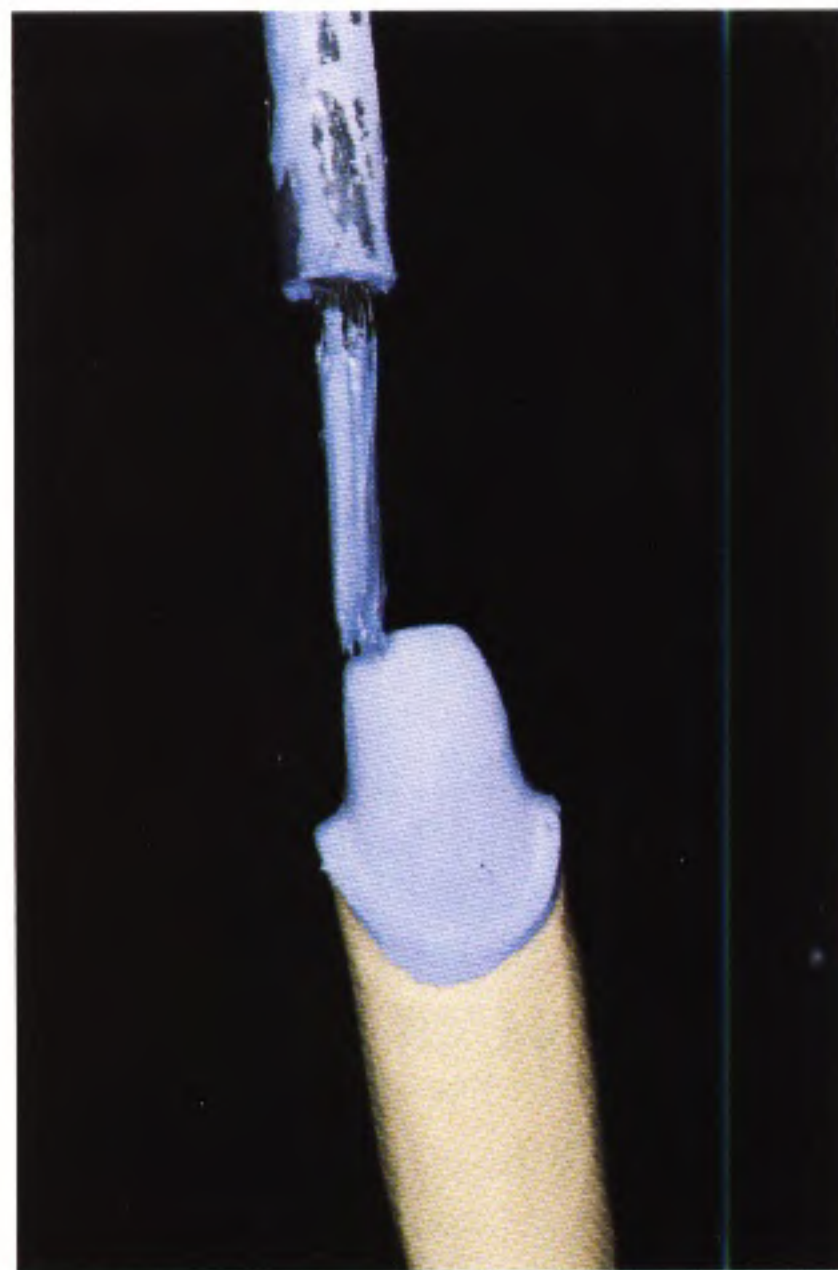


Fig 7-15 Gypsum die painted with AccuFilm IV (Parkell).

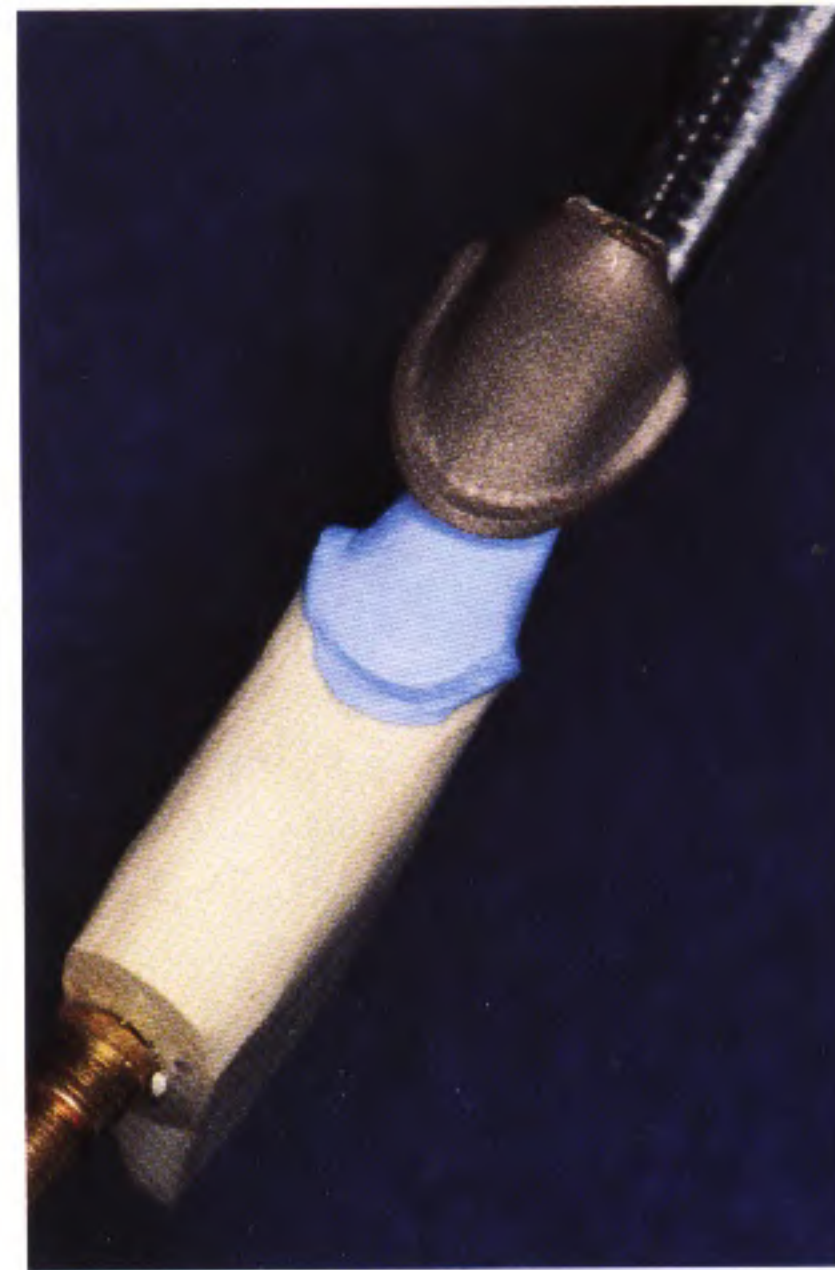


Fig 7-16 The casting is gently and slowly placed on the die.

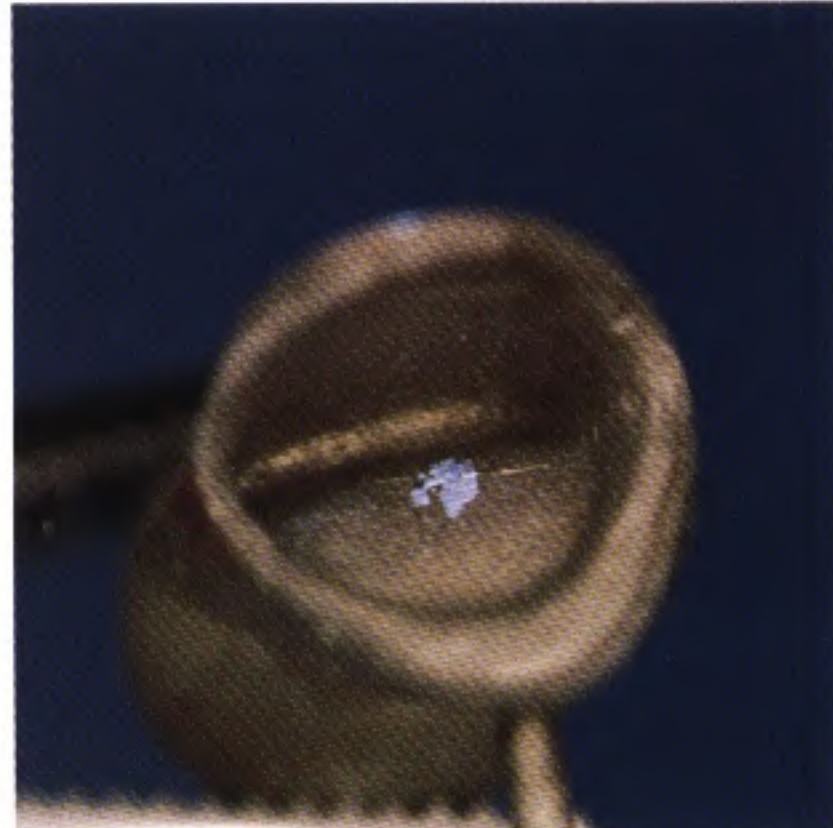


Fig 7-17 The casting is removed if resistance is met, or it is seated completely if there is no resistance. Areas of binding will transfer the disclosing medium from die to casting.

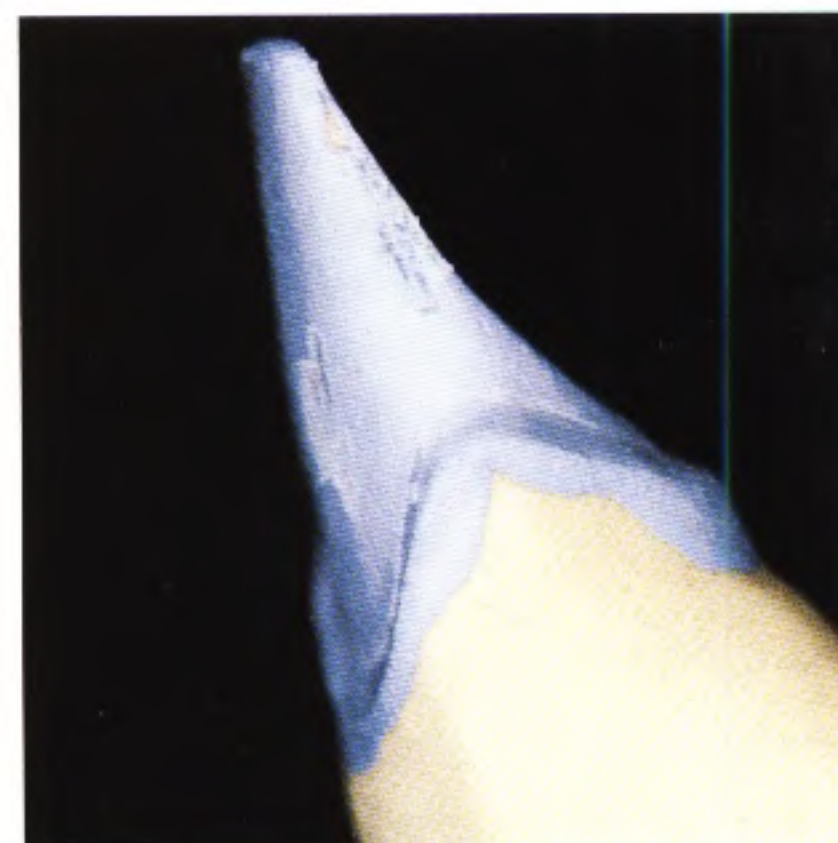


Fig 7-18 In some instances, the die itself may be slightly abraded, indicating an adjustment is needed.



Fig 7-19 Adjust the inside of the casting with a small carbide bur in an electric handpiece.

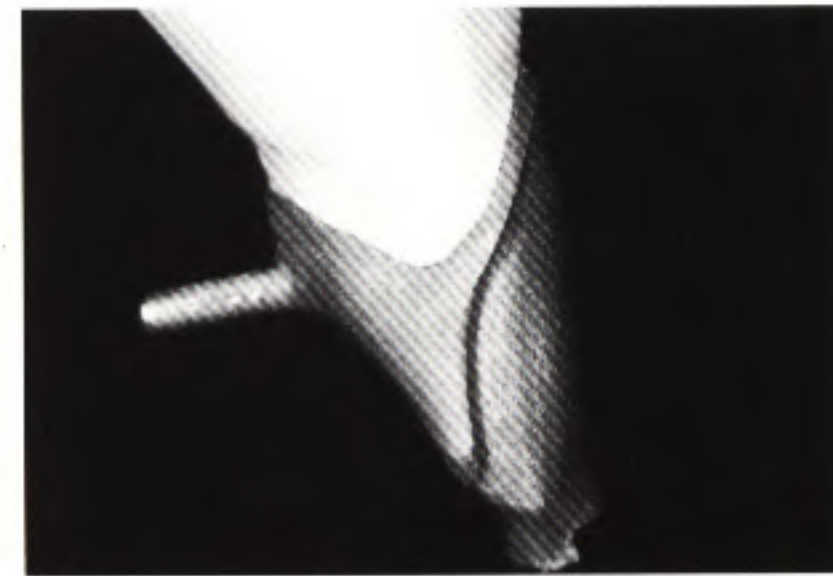


Fig 7-20 Lateral view of the casting completely seated.



Fig 7-21 After de-spruing, the sprue area is finished with a heatless stone (Mizzy USA).



Fig 7-22 The metal calipers should be used to measure the thickness of metal before any adjustments are made (Iwanson gauge, Pfingst Co). Hold the gauge securely and allow the movable area to close on the casting. The thickness of metal will be indicated on the scale at the base of the gauge.



Fig 7-23 For gross finishing use a heatless stone to go over the facial surface.

master cast and properly articulated. Also, if the casting has suck-back porosity at the junction of the sprue and restoration, it may not be apparent until this area is finished. It is best to know now if such porosity is present in the casting rather than to find out after you have adjusted and finished the restoration.

Finishing the porcelain-bearing surface

You are now ready to begin the rough finishing of the restoration. Start by using the Iwanson gauge to measure the thickness of metal across the entire porcelain-bearing surface (Fig 7-22). If there are any areas that require reduction, finish them first. If you have cut back the wax appropriately in the waxup stage, some areas may be thicker than others in order to have a uniform thickness of porcelain. Should you find an excessively thick area, adjust it to the appropriate dimension for the clinical case and the type of alloy used.

During any adjusting and finishing procedure it is important to remember to periodically check the thickness of the casting with metal calipers to be sure that the metal is not overreduced. Failure to make frequent checks of the metal thickness can very easily lead to perforation of the substructure. Very small perforations can be repaired by presoldering, although it is best to remake the entire crown if the hole is extensive or if a large area has been thinned excessively and has weakened the substructure. For best results, be sure to review all the substructure design guidelines before you begin the finishing process. You do not want to have any sharp angles or

concavities, but you do want a sharp, well-defined butt joint at the porcelain-metal junction.

Use a heatless stone to perform any gross reduction of extensive axial surfaces (Fig 7-23) and check the thickness of the area where the sprue was attached. Once you are satisfied with the axial contour and the rough metal finish, you can begin the final preparation of the porcelain-bearing surface of the restoration.

This finishing procedure will serve several functions. It will:

1. Smooth the porcelain surface, making it free of sharp angles
2. Create microscopic undercuts (as mentioned in chapter 6); these microscopic undercuts will provide mechanical retention and will increase the surface contact area for the dental porcelain veneer
3. Reduce the contact angle of the porcelain as it is being applied

Although the finished surface is slightly rough to provide mechanical retention, it will allow the dental porcelain to readily wet the metal.

Abrasive selection is very critical, so use a clean ceramic-bound abrasive that has never been used to finish any other type of casting alloy. Avoid any possibility of metal cross-contamination by keeping your abrasives separated for different types of alloys. Stock abrasives can be reshaped with a sharpening stone if desired (Fig 7-24).

When grinding there is always the possibility that haphazard finishing in many directions may trap de-

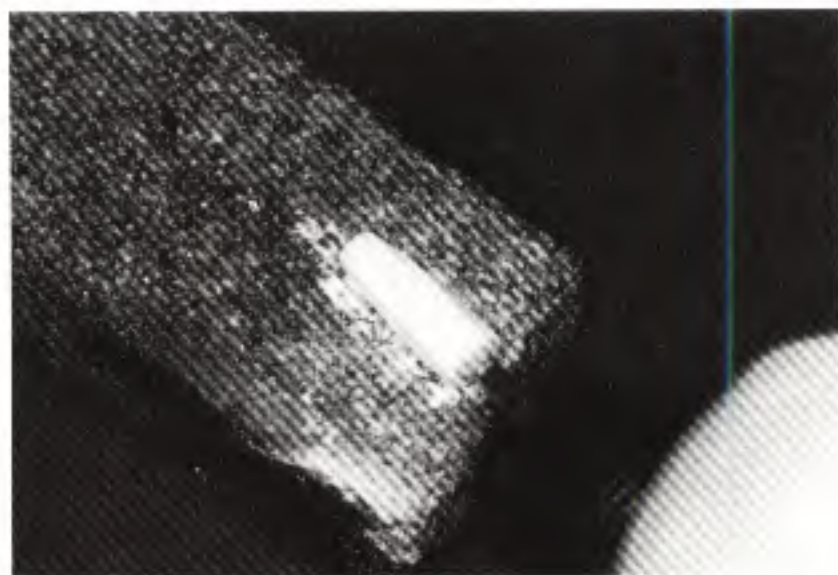


Fig 7-24 Use a sharpening stone to adjust a large ceramic stone to your preferred shape and size.

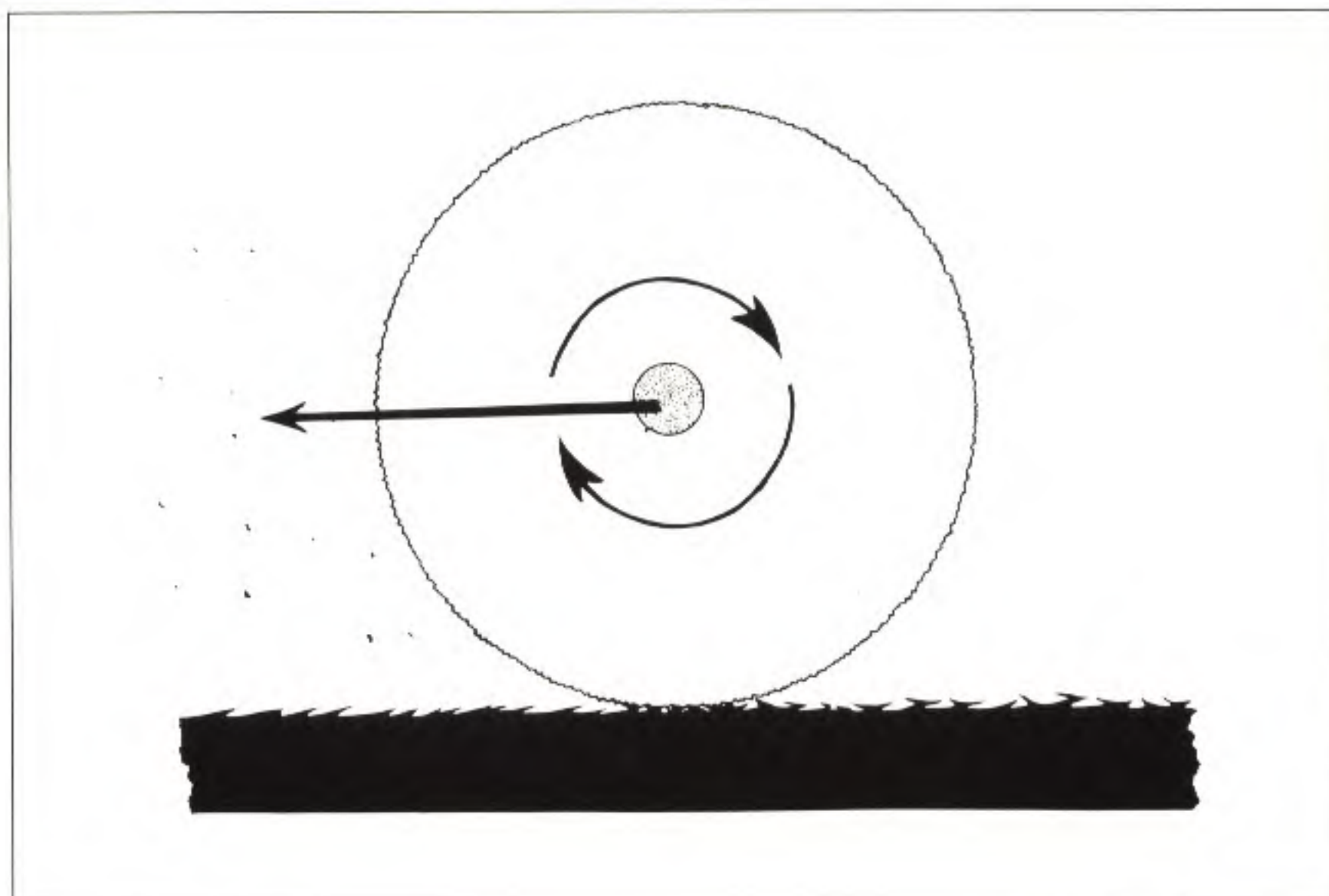


Fig 7-25a Avoid finishing in many directions because this will create irregularities on the metal surface.

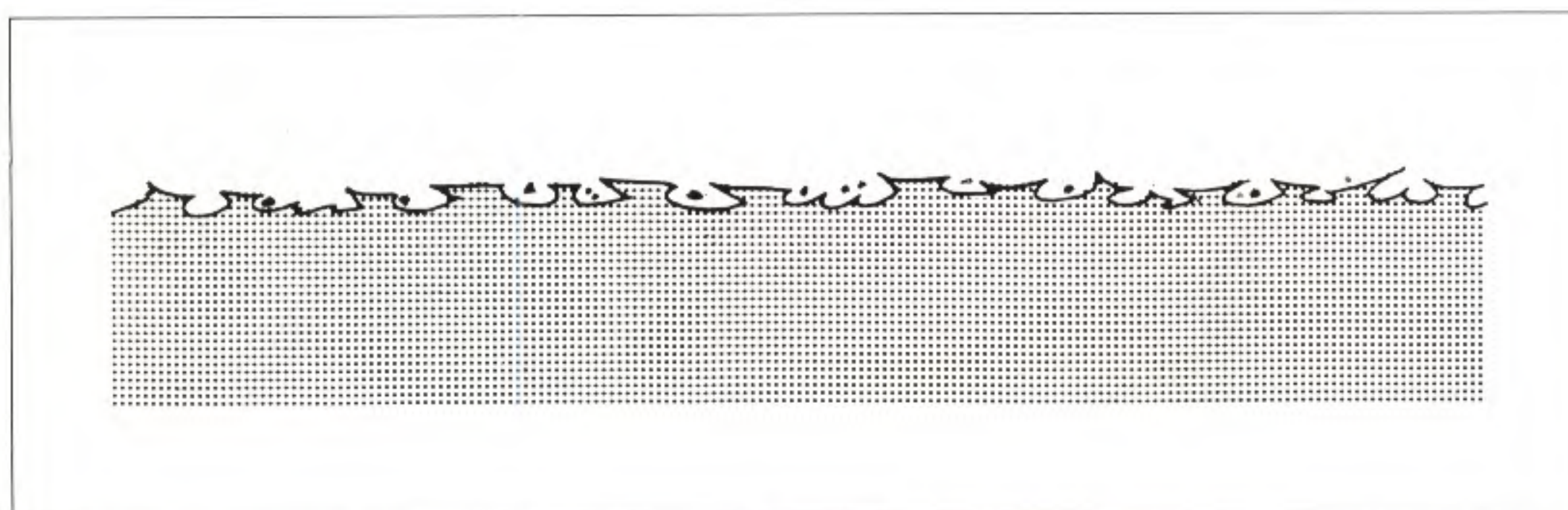


Fig 7-25b Some of the irregularities may retain debris that can later contaminate the porcelain.

bris in the surface irregularities (Figs 7-25a and b). This effect can be minimized simply by finishing the porcelain-bearing surfaces in one direction (Fig 7-26). By rotating the abrasive toward you, the alloy is pulled in your direction to readily reduce the surface irregularities and to remove debris (Figs 7-27 and 7-28).

A properly finished porcelain-bearing area should have a smooth, satin finish, but do not use an abrasive finer than a fine ceramic stone (Fig 7-29). By all means, do not use a rubber wheel to smooth this area, because it will contaminate the metal with its residue. A rubber wheel will also reduce the mechanical undercuts on the surface and increase the contact angle of the porcelain mixture, adversely affecting the wettability of the ceramic during sintering.

Extra attention must also be given to the thin facial metal collar. You may have waxed the collar wider than 0.5 mm. As a general rule, the labial metal collar is waxed to equal the width of the labial bevel. Techni-

cally, a 0.5-mm beveled tooth preparation will require more than a 0.5-mm metal collar (McLean, 1979). The true width of the collar should include the height of the bevel externally plus some dimension for the thickness of the metal substructure. If you wish to reduce the width of the metal collar, now is the time to do so. A straight shank no. 8 round carbide bur is recommended for this procedure (Fig 7-30). To avoid damaging the restoration, always select a sharp bur and make certain the bur cuts towards you. This procedure is best accomplished using a microscope (Fig 7-31). If the metal collar is reduced below the 0.5-mm dimension, the facial porcelain placed in that area will lack proper bulk and be subject to stresses if the thinned metal flexes. Of course, if there is no facial bevel on the preparation, the metal collar can be thinned to 0.3 mm if so desired. Recheck the thickness of the porcelain-bearing areas.



Fig 7-26 With the stone rotating counterclockwise, begin finishing at the porcelain-metal junction opposite you. Move the stone across the metal surface towards you. When you reach the porcelain-metal junction nearest you, stop and repeat the process so the direction of finishing is always toward you.

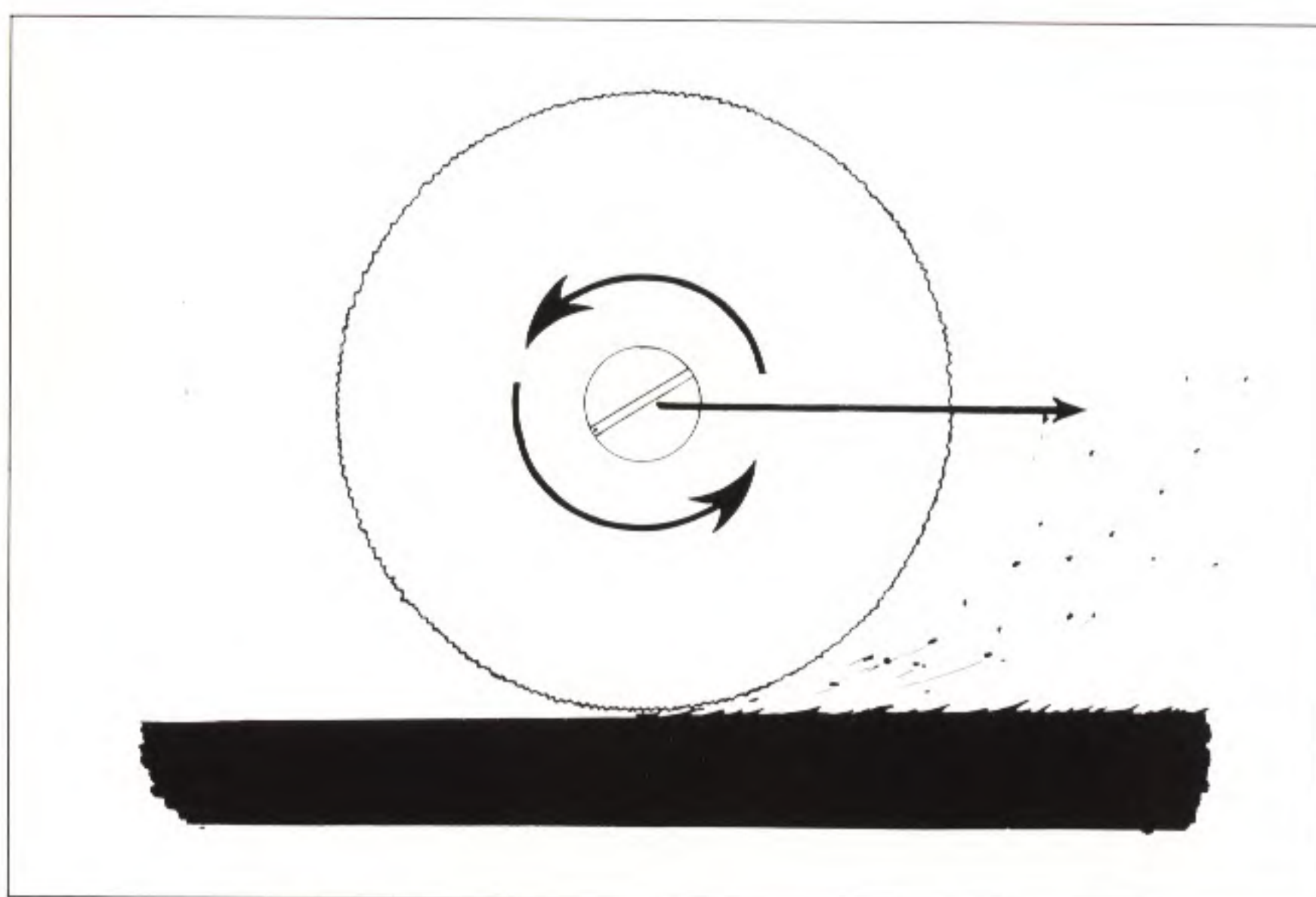


Fig 7-27 Finish the metal in one direction. Unidirectional finishing should leave the metal surface smooth and free of debris.



Fig 7-28 Finish the lingual aspect of the incisal area in one direction as well.

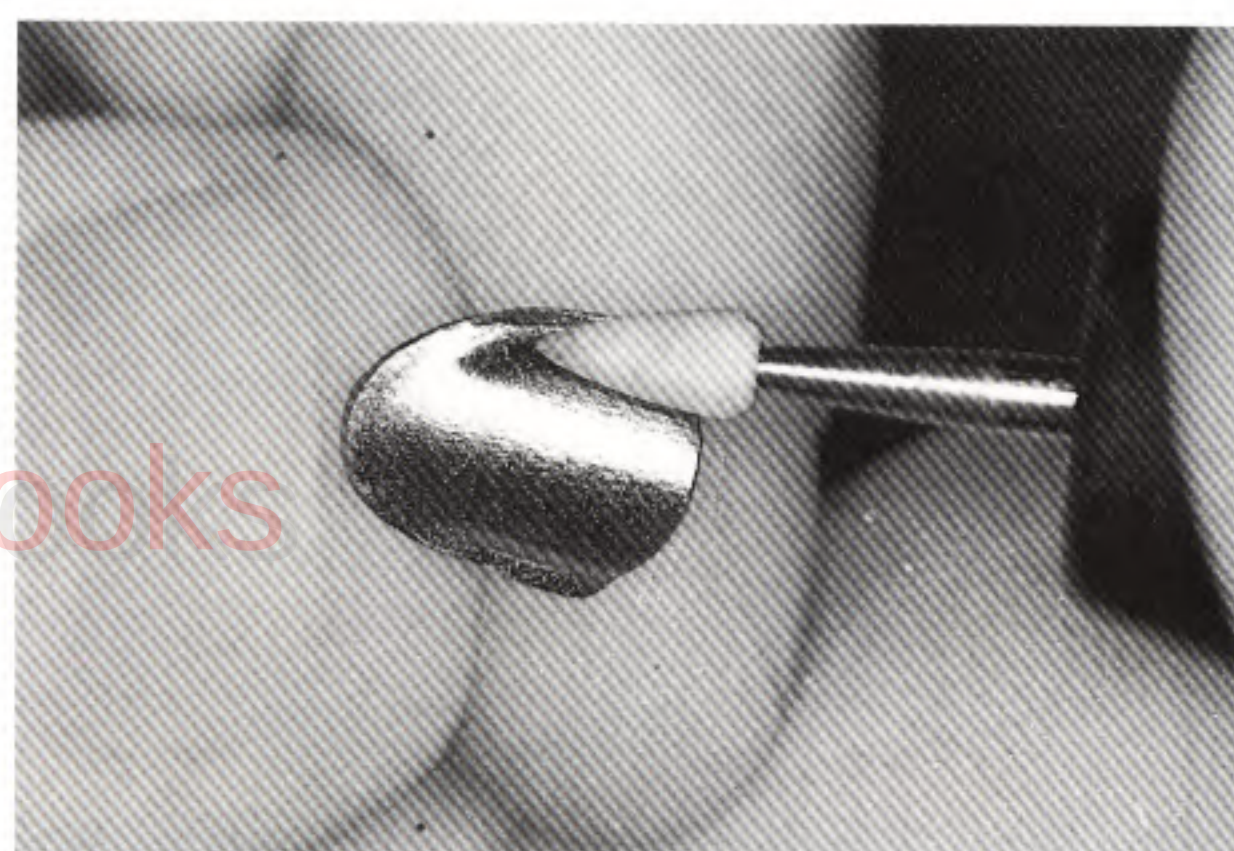


Fig 7-29 When performed correctly, the metal surface will be smooth and have a satin finish to it. Use a fine ceramic stone to smooth the metal and remove any minor irregularities while creating greater uniformity to the surface finish.

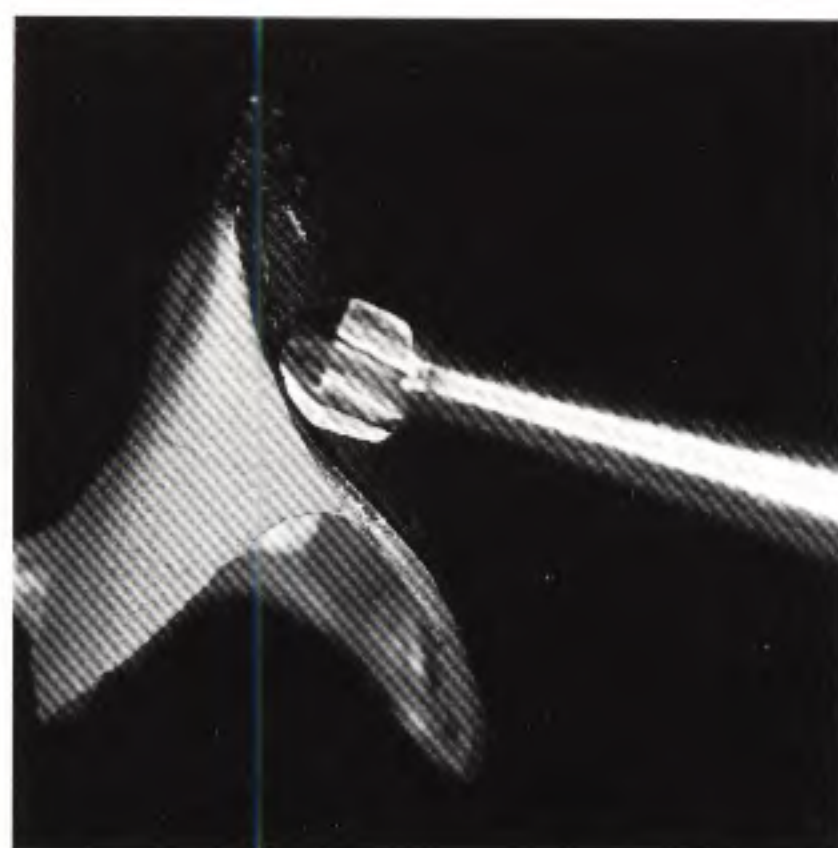


Fig 7-30 The sharp external line angle of the porcelain-metal junction can be restored or refined with a no. 8 round carbide bur especially across the facial metal margin.

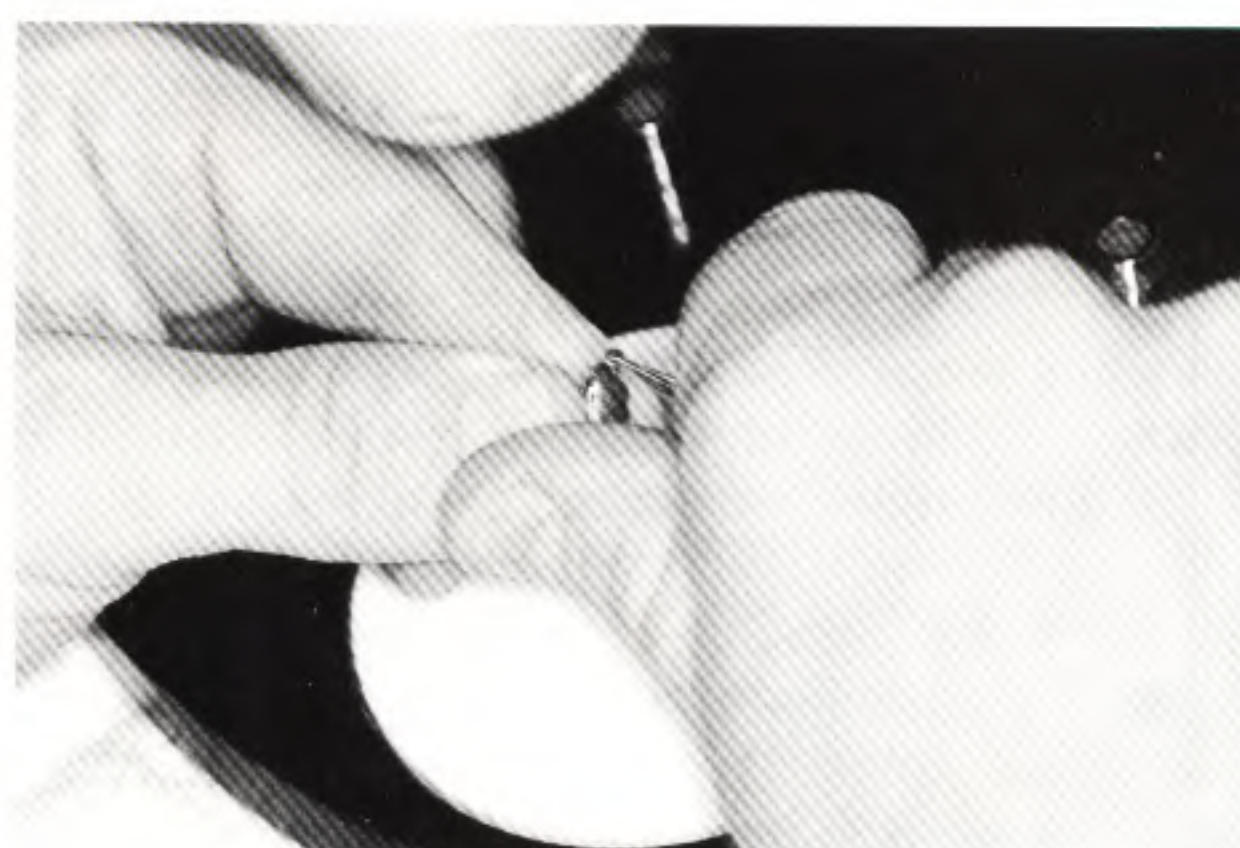


Fig 7-31 Protect the margins of the casting and slowly refine the metal collar and porcelain-metal junction in the interproximal areas.

Finishing the nonporcelain-bearing surfaces

The last step in preparing the metal substructure is to finish the nonporcelain-bearing surfaces (Fig 7-32). There are two differing philosophies on this aspect of metal preparation. One approach is to minimize the finishing of all nonporcelain-bearing areas until after the porcelain has been built up, contoured, and glazed. It is believed that anything other than a light finishing of the nonporcelain-bearing areas will promote surface oxidation and increase the risk of contaminating those surfaces that are to receive porcelain.

The second approach requires preliminary finishing of all nonporcelain-bearing areas through the rubber wheel stage (Rosenstiel et al, 1988). There are two important benefits to rubber wheeling these surfaces at this point. First, any rough areas and scratches can be eliminated before the porcelain has been applied; this will reduce the possibility of the ceramic veneer becoming contaminated during the final polishing. Second, preliminary polishing of the nonporcelain-bearing areas now may actually prevent some problems from occurring in a subsequent procedure. Opaque porcelain is very coarse and cannot be glazed, so it must be completely covered with a layer of dentin or enamel porcelain. Any excessive finishing of the nonporcelain-bearing surfaces after the porcelain buildup could possibly expose the opaque layer at the porcelain-metal junction.

Be sure to place the restoration on the cast, check the occlusion, and adjust any occluding surfaces according to the predetermined occlusal scheme. Use a ceramic abrasive to rough finish the metal lingual and axial surfaces. After this step, switch to a finer ceramic stone (Fig 7-33). At this point you may simply air-abrade and clean the restoration in preparation for oxidation or continue finishing the nonporcelain-bearing area with rubber instruments. One concern is that rubber finishing now could possibly contaminate the metal surface. On the other hand, the restoration will be air-abraded and steam cleaned or ultrasonically cleaned prior to oxidation so contamination should not be a problem. If you choose to smooth the nonporcelain-bearing surfaces now, use a rubber point to refine the lingual anatomy (Fig 7-34) and a rubber wheel to go over axial surfaces (Fig 7-35).

Refine the porcelain-metal junction again if you need to restore the 90-degree butt joint (Fig 7-36). The porcelain-bearing surface should now have a satin finish and the nonporcelain-bearing areas should be smooth (Fig 7-37). Do not use any polishing agents (buffing bar compound, tripoli, or rouge) at this time.



Fig 7-32 The nonporcelain-bearing area can either be air-abraded and cleaned or rubber polished to remove scratches and irregularities before the porcelain is applied. Identify the location of occlusal contacts before you begin the polishing procedure.



Fig 7-33 If the lingual surface is rough or contains irregularities, use a brown stone. Otherwise, a smooth casting generally will only require a gentle finishing with a fine white ceramic stone.



Fig 7-34 Follow the fine ceramic stone with a green polishing point.

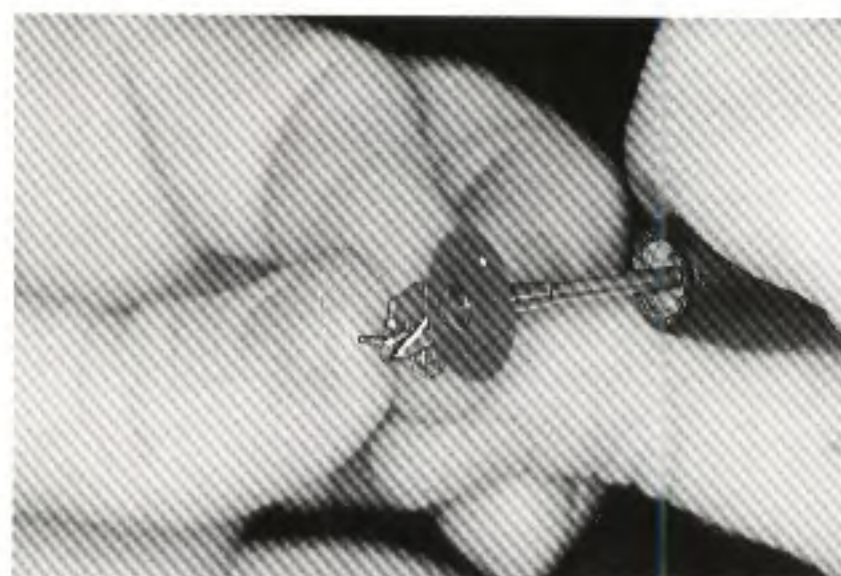


Fig 7-35 Use the rubber wheel to smooth axial surfaces.



Fig 7-36 Polishing may have rounded the porcelain-metal junction, so refine the porcelain-metal junction with a no. 8 round carbide bur.



Fig 7-37 Facial view of the porcelain-bearing area of the finished substructure.



Fig 7-38 Facial view of a properly air-abraded substructure on the master cast.



Fig 7-39 Steam clean the substructure after air-abrading with aluminum oxide. As a matter of safety and to avoid potential injuries, perform any steam cleaning procedure over a sink and out of the way of other personnel.

Cleaning procedures

After the substructure has been adjusted and finished it is important to clean the work thoroughly. First, air-abrade the porcelain-bearing surfaces (Fig 7-38) with 50- μ m, nonrecycled, pure aluminum oxide (see Fig 5-23 in chapter 5). Next, steam clean the entire work or ultrasonically clean it in distilled water for 10 to 15 minutes (Fig 7-39).

Oxidizing the anterior single-unit restoration

The finished and cleaned substructure should be of the appropriate thickness for the type of casting alloy used and the clinical case requirements (Fig 7-40). Assuming no additional changes are necessary, the substructure is ready to be oxidized. Take special care not to touch the porcelain-bearing areas with your fingers for fear of contaminating these surfaces with oils and debris.

Place the cleaned castings on a saggar tray (Fig 7-41) and oxidize the metal substructure according to the manufacturer's directions (Fig 7-42).

Finishing other types of single-unit restorations

The technique illustrated for fitting, adjusting and finishing, and oxidizing the prepared metal substructure can also be applied to the other types of restorations described in chapter 4 (ie, anterior substructure with a porcelain lingual surface, posterior substructure with a metal occlusal surface, and posterior substructure with a porcelain occlusal surface). These restorations should be finished to create a smooth surface, air-abraded, and oxidized using the same technique for the single-unit anterior restoration.



Fig 7-40 Make a final check of the metal surface with the Iwanson gauge. A metal thickness of no less than 0.3 mm is preferred for most single units.

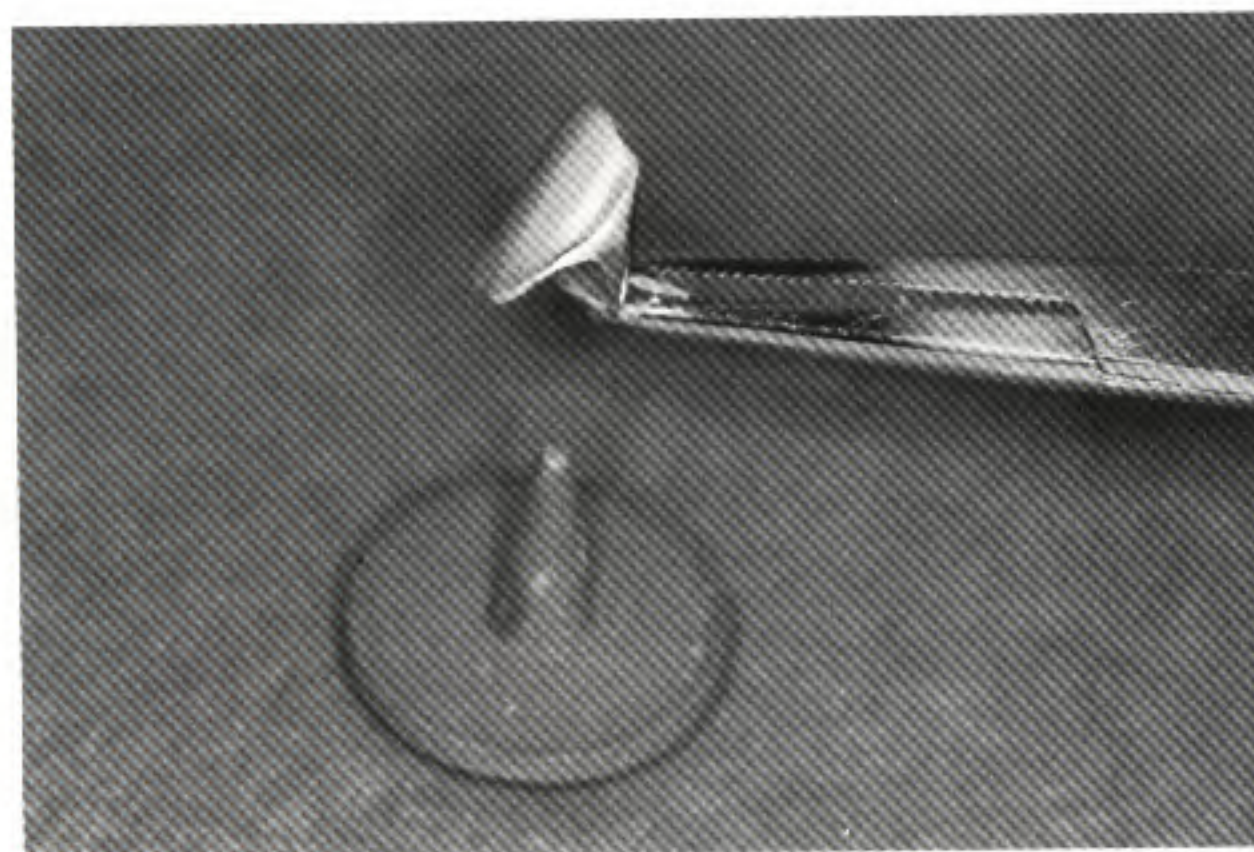


Fig 7-41 Using the cast 18-gauge handle, carefully place the cleaned casting on an individual saggar tray (Vident).

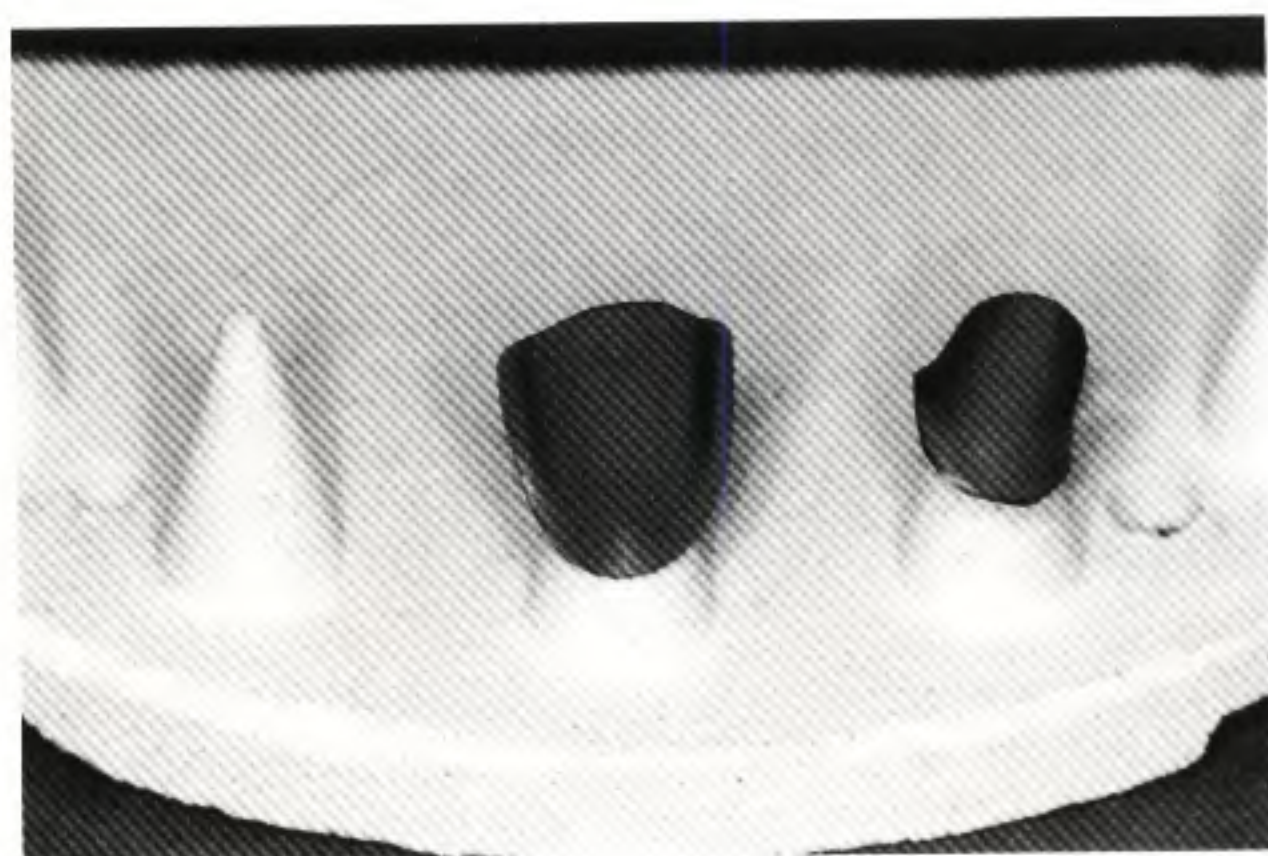


Fig 7-42 Multiple units can be placed on a larger saggar tray (J.F. Jelenko & Co) and oxidized together. These castings made from Protocol (Williams Dental Co) were oxidized at 1,010°C for 5 minutes under vacuum.

Finishing a fixed partial denture

The technique for finishing a fixed partial denture is similar to the procedures used for a single-unit restoration. Carefully cut the sprues and remove the cast fixed partial denture (Fig 7-43). Inspect the inside of the retainers under a microscope or with loupes and remove any nodules or other obvious defects (Fig 7-44). Do not immediately attempt to seat the prosthesis on the master cast because the restoration may not fit. You must first determine if the retainers need adjustment or if the casting is distorted.

The first step in finishing a fixed partial denture is to fit the retainers individually. Each retainer should be adjusted in the same manner used for a single-unit crown (Figs 7-45a and b). After you have separately fit the retainer castings, carefully attempt to seat the

entire restoration on an uncut master cast or a master cast with very stable dies (Fig 7-46). Do not use pressure to seat the prosthesis; if the casting does not fit, the die could be abraded or irreparably damaged quite easily.

Once the fixed partial denture is in place, gently press down alternately on each abutment to determine if the restoration fits securely (Figs 7-47a and b). If the prosthesis is ill-fitting, it will probably "rock" on the cast when the retainers are alternately depressed one after another (Figs 7-48a and b). If the fit is not completely satisfactory, use an ultra-fine, cut-off disk and cut through one of the connector areas (Fig 7-49) and presolder the prosthesis. If the fit is acceptable, continue with the metal finishing procedure by following the same steps and using the same technique just described as for a single-unit crown (see Figs 7-21 to 7-40).

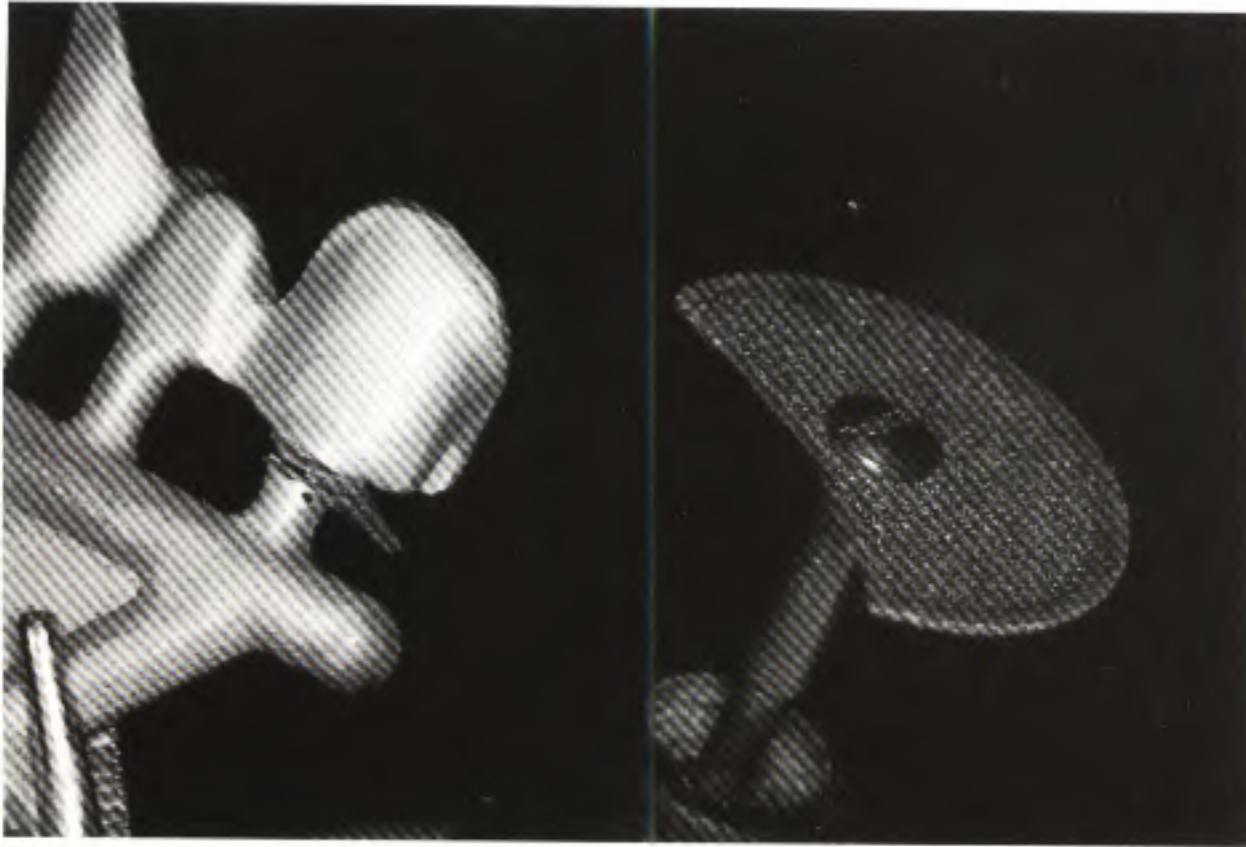


Fig 7-43 Additional care must be taken when de-spruing a fixed partial denture, because it is easier to break carborundum disks. After you make cuts on both the facial and lingual aspects, rock the prosthesis backward and forward to separate it from the runner bar.



Fig 7-44 Use a microscope to inspect the fixed partial denture casting inside and outside.



Fig 7-45a Carefully seat each fixed partial denture retainer on its individual die.



Fig 7-45b Examine the intaglio (internal) surface of each retainer for areas where the disclosing medium (AccuFilm IV, Parkell) has been transferred from die to casting. Adjust the marked areas with a small round carbide bur.



Fig 7-46 Once adjusted, verify the fit of the fixed partial denture on the master cast.



Fig 7-47a (left) To make certain the one-piece framework does not rock, lightly depress the anterior retainer and observe the distal retainer.

Fig 7-47b (right) Next, lightly depress the distal retainer and observe the prosthesis for evidence of rocking.



Fig 7-48a If the one-piece framework fits the cast well when the opposite incisor retainer is depressed, no movement should be detected in the canine retainer.



Fig 7-48b On the other hand, if the prosthesis is ill-fitting, the canine retainer will be lifted from its die when the incisor retainer is depressed. This framework should be sectioned and presoldered.



Fig 7-49 Carefully inspect the framework and section the connector with the least desirable dimensions of occlusal-lingual height and buccal-lingual width, and use the presoldering procedure to correct any discrepancies.

Soldering fixed partial dentures

Several situations involved in fabricating fixed partial dentures require a soldering procedure to complete the case. Three examples that you are most likely to encounter include, but are not limited to, the following.

1. You may find that a fixed partial denture framework cast entirely in a ceramic alloy may not fit the cast as well as you would like.
2. The case may be complicated or the prosthesis so large that you plan to presolder two components rather than attempt to cast them in one piece.
3. There may be cases where you have to join dissimilar metals. With posterior restorations, joining alloys of different compositions might involve soldering a Type III or Type IV gold retainer to a metal ceramic component.

When the soldering procedure performed involves uniting components of the same alloy before the porcelain is fired to the substructure, that process is referred to as presoldering. The solder used for presoldering is a high-fusing solder similar in composition to the parent alloy of the components to be joined. With presoldering you must use a high-temperature, phosphate-bonded soldering investment. If the components to be joined are made of different alloys (eg, Type III or Type IV gold and a ceramic alloy) or the porcelain has been completed (glazed) and the metal polished, you must use a low-fusing gold solder and postsolder the components. The term *postsoldering* is used because the soldering process occurs after the ceramic veneer has been glazed and the work is essentially complete (the metal has been polished). With postsoldering, a low-temperature, gypsum-bonded soldering investment can be used to avoid damage to the glazed surface.

Because most situations requiring the soldering of a metal ceramic fixed partial denture occur before the application of porcelain, only the presoldering procedure will be discussed.

Presoldering a fixed partial denture

The most common situation that warrants soldering is when the fixed partial denture framework does not fit the uncut master cast but does fit the individual dies. In this instance, you have two choices: you can either rewax and recast the work, or you can section and presolder the prosthesis. However, if a fixed partial denture has been cast in one piece and does not fit, it should be presoldered immediately after the connector has been cut. Do not continue finishing the restoration until after it has been soldered and the proper fit of the restoration confirmed. The added bulk of metal will provide strength to the prosthesis and help it resist exposure to the high soldering temperatures. Regardless of whether it was intentional or necessary, presoldering is a relatively simple procedure with most metal ceramic alloys.

Materials

You must select the appropriate solder and soldering investment for the type of alloy you are using. High-fusing metal ceramic alloys require a phosphate-bonded soldering investment such as Unitek's High-Heat Soldering Investment (3M/Unitek). This type of refractory material resists slumping when mixed properly, has minimal expansion, and is stable at the high temperatures required to join high-fusing metal ceramic alloy components.

The presolder you choose must be matched to the parent alloy. For best results, use the presolder rec-

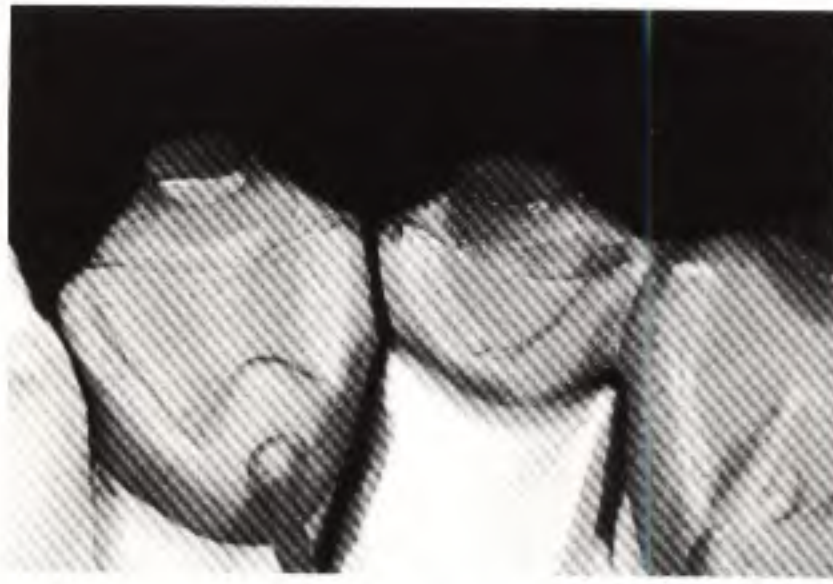


Fig 7-50 The two components of the fixed partial denture are repositioned on the master cast.

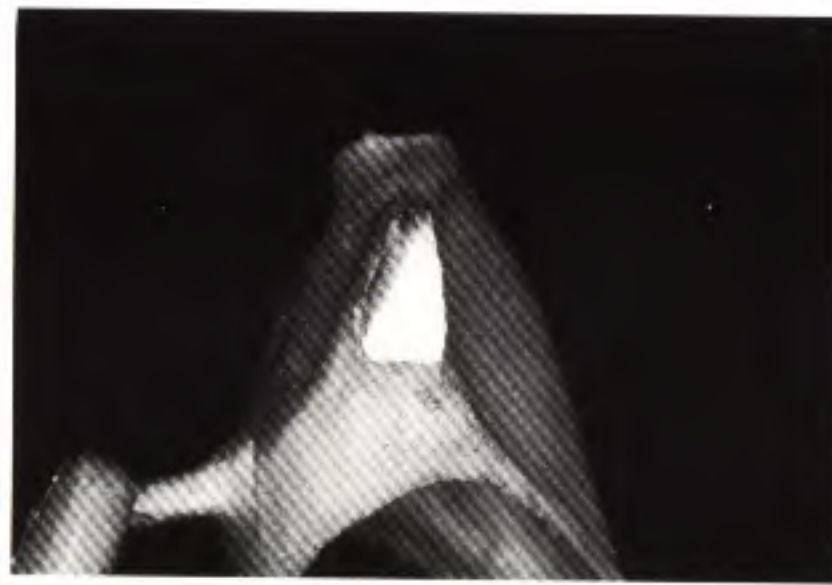


Fig 7-51 A properly finished surface of a connector area. Note the triangular form of the joint, which provides sufficient height and breadth for anterior restorations.



Fig 7-52 Use the metal calipers to measure the thickness of the solder strip (Iwanson gauge, Pfingst Co). This strip of presolder measures 0.3 mm in thickness.



Fig 7-53 Use the 0.3-mm-thick solder strip to size the solder gap. If the strip cannot be inserted into the solder gap, the area should be enlarged slightly for this type of alloy. If a solder gap less than 0.3 mm is desired, adjust the thickness of the solder by lightly grinding on the sides of the strip.



Fig 7-54 This gap is too small and will not provide for a sufficient amount of solder. It should be opened to approximately 0.3 mm for this high palladium-silver-gold alloy.



Fig 7-55 This solder gap is larger than desired.

ommended by the alloy manufacturer. Presolders are carefully formulated to melt several hundred degrees below the parent alloy and several hundred degrees above the fusion temperature of the dental porcelain.

Adjusting the solder gap

Select the least desirable connector area and section the fixed partial denture in this area. After all, if you are going to solder a connector you may as well replace a joint that was less than ideal. Then make certain the individual retainers seat completely on their respective dies on a stable master cast (Fig 7-50). Any discrepancies in seating or orientation obviously will result in a poorly fitting restoration.

Next, check the internal surfaces of the solder gap. They should be smooth and lightly finished (Fig 7-51) with a rubber wheel (Eissmann et al, 1980) or fine sandpaper disks (Shillingburg et al, 1981). In order to provide adequate room for the solder, the gap should be opened to approximately 0.3 mm (Figs 7-52 and 7-53). If the solder gap is too small, the setting and thermal expansion of the soldering procedure will close the gap to the point where the investment will crack (Fig 7-54). If the gap is too large, an excessive amount of solder is needed to fill the space and the connector will be weak (Fig 7-55). Recommended gap distances vary with the different casting alloys, so consult the manufacturer of your alloy for specific recommendations.

Preparing the solder

There are at least three different methods to gauge the amount of solder needed for a particular connector area. The first and least complicated is freehand soldering, which involves little preparation. You simply apply a solder strip to the heated connector area and allow the torch tip to heat the solder freely (Fig 7-56). This technique is fast and easy, but you do run the risk of applying too much solder to the joint area.

A second and more predictable technique is to cut a length of solder and fit it to the actual gap to be soldered. With the sectioned fixed partial denture seated securely on the master cast, first attempt to place the solder in the top of the prepared joint. Use an adjusting stone to adjust the solder gap until it can

accept the solder strip and retain it, or adjust the solder strip if a gap of less than 0.3 mm is required. Cut the end of the solder strip so it extends several millimeters beyond the top of the connector area (Fig 7-57). The cut and adjusted piece of solder should contact the two components to be joined and remain in position after placement.

A third method is to create a "tadpole" piece of solder. Place one end of a solder strip in the flame of a soldering torch and remove it from the flame after the end rounds (Fig 7-58). Cut the "tadpole" end from the strip and adjust that end of the solder strip so the head of the "tadpole" extends above the connector area and the cut end extends below the components to be joined (Figs 7-59a and b).



Fig 7-56 An example of soldering freehand.



Fig 7-57 Cut a length of solder with wire cutters. To provide sufficient bulk of solder, the solder should be cut so the piece extends beyond the bottom of the connector area and several millimeters above the incisal edge.



Fig 7-58 Insert one end of the solder strip in a properly adjusted torch until the end rounds. The rounded end of the solder strip after heating.



Fig 7-59a Cut off the "tadpole" end of the solder strip with the wire cutters.

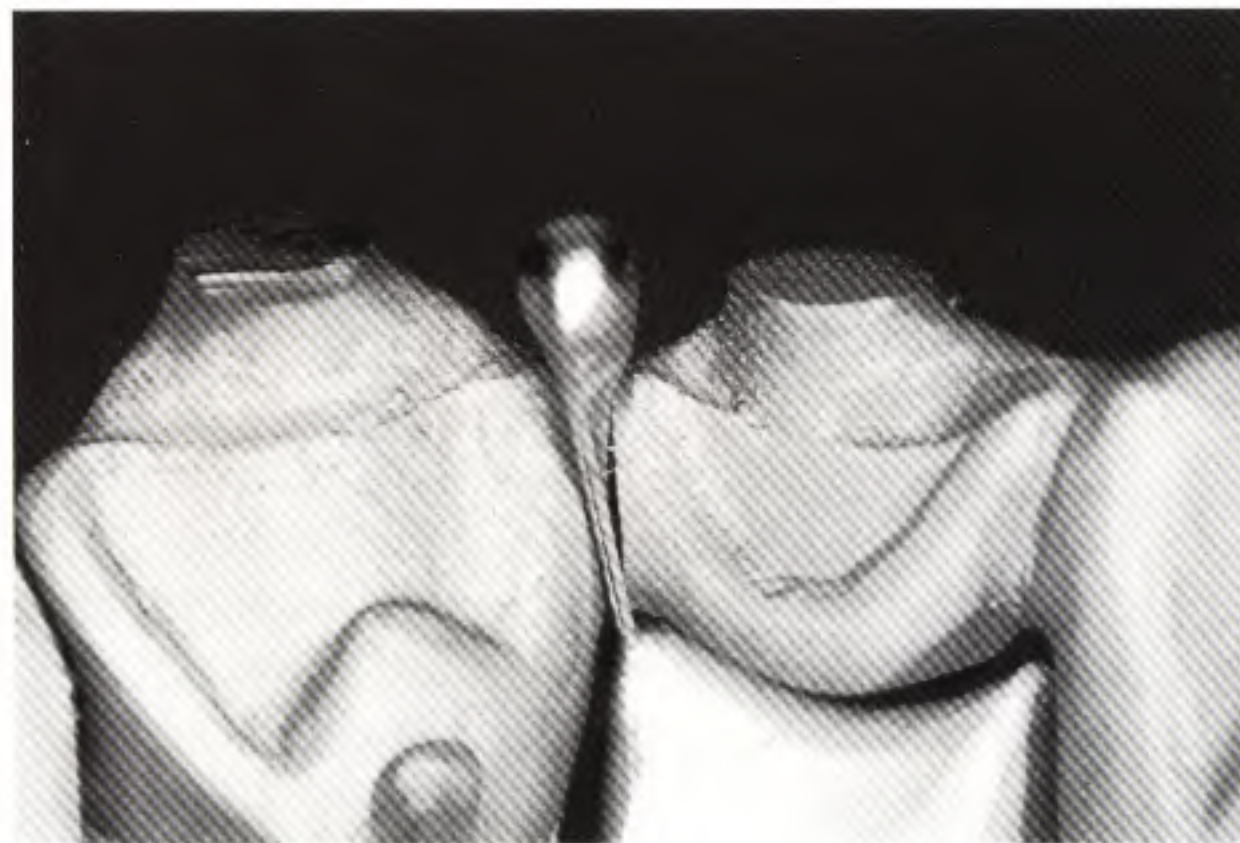


Fig 7-59b Place the solder in the prepared joint space so the "tadpole" head lies above the incisal edge while the cut end extends beyond the full length of the connector area to provide sufficient bulk of solder for the gap.

Luting the restoration

To obtain an accurate solder relationship, you must have a master cast that is an accurate replica of the patient's mouth. If necessary, trim the tissue area away from prepared tooth and seat the casting. In the laboratory, you can use a solid cast without removable dies poured directly from the impression or a master cast with stable working dies. In the event the cast or the removable dies have been damaged or the dies are not stable and you are unable to pour an additional accurate cast from the impression, you will have to obtain a solder index directly from the patient.

With the units seated on the cast, you can make a stone index directly from the working cast with the restoration in place or you can use a material with minimal setting expansion to lute the two components together (Malone et al, 1989). An impression plaster has been recommended because it is dimensionally accurate, but acceptable luting materials such as

some acrylic resins (Duralay, Reliance Dental Mfg Co) (Malone et al, 1989; McLean, 1980), or a cyanoacrylate cement can be used. Do not use any form of sticky wax or modeling plastic because these materials will not provide the desired level of dimensional stability. Place a small quantity of Duralay powder and liquid in separate dappen dishes (Fig 7-60). Moisten the connector area with liquid monomer (Fig 7-61a). With a moistened brush, pick up a small quantity of powder so the material is readily wetted. Place the mixture at the top of the connector area (Fig 7-61b) and allow it to flow down into the joint (Fig 7-61c). Move the brush quickly through the powder to avoid the formation of a large clump of resin (Fig 7-62), but make certain the mix is not so dry as to inhibit its flow.

After the units have been properly luted together, immediately invest the fixed partial denture to minimize any potential for distortion.



Fig 7-60 Use an acrylic resin with low polymerization shrinkage to lute the metal components together (Duralay, Reliance Dental Mfg Co). To lute the fixed partial denture, dispense a small quantity of Duralay powder and liquid in separate dappen dishes or similar dishes and select a small, clean brush.



Fig 7-61a Use the small brush to wet the connector area with monomer.



Fig 7-61b Lightly dab a moistened brush into the Duralay powder to create a small, moist ball of resin on the brush tip. Place the small ball of resin at the incisal edges of the connector areas and let it flow down into the gap.



Fig 7-61c A properly luted joint should be neat, free of excess material, and provide sufficient bulk for strength, no more and no less.



Fig 7-62 Do not plunge the wetted brush into the acrylic resin powder or you are likely to have too much material on your brush. If the resin is too dry it will bead up and not flow into the gap. Either rewet the mix or start again and obtain a wetter mix.

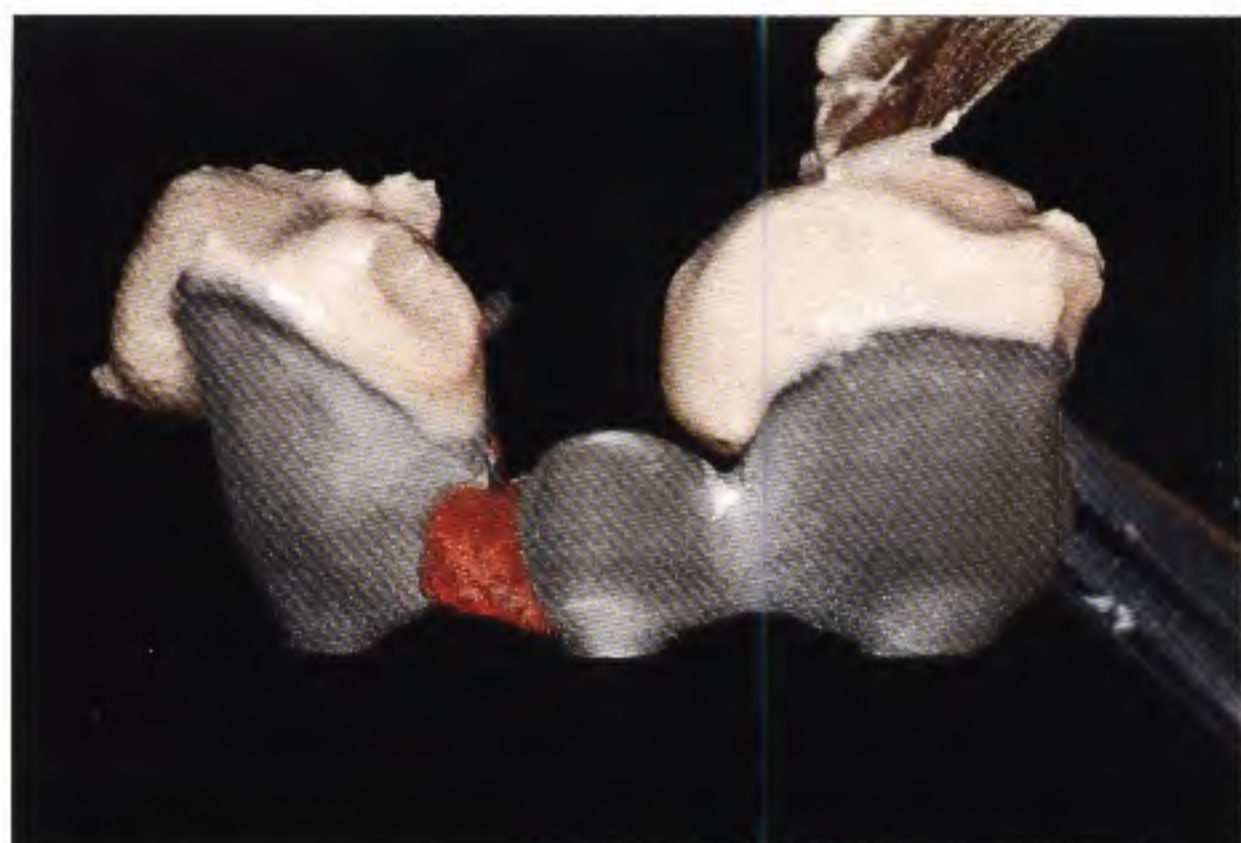


Fig 7-63 For small fixed partial dentures, fill the individual retainers with presoldering investment and protect the crown margins.



Fig 7-64 The invested fixed partial denture before trimming. Note that a V-shaped groove has been created under the connector area so the torch flame will be able to heat the metal components easily yet some investment still supports the pontic.

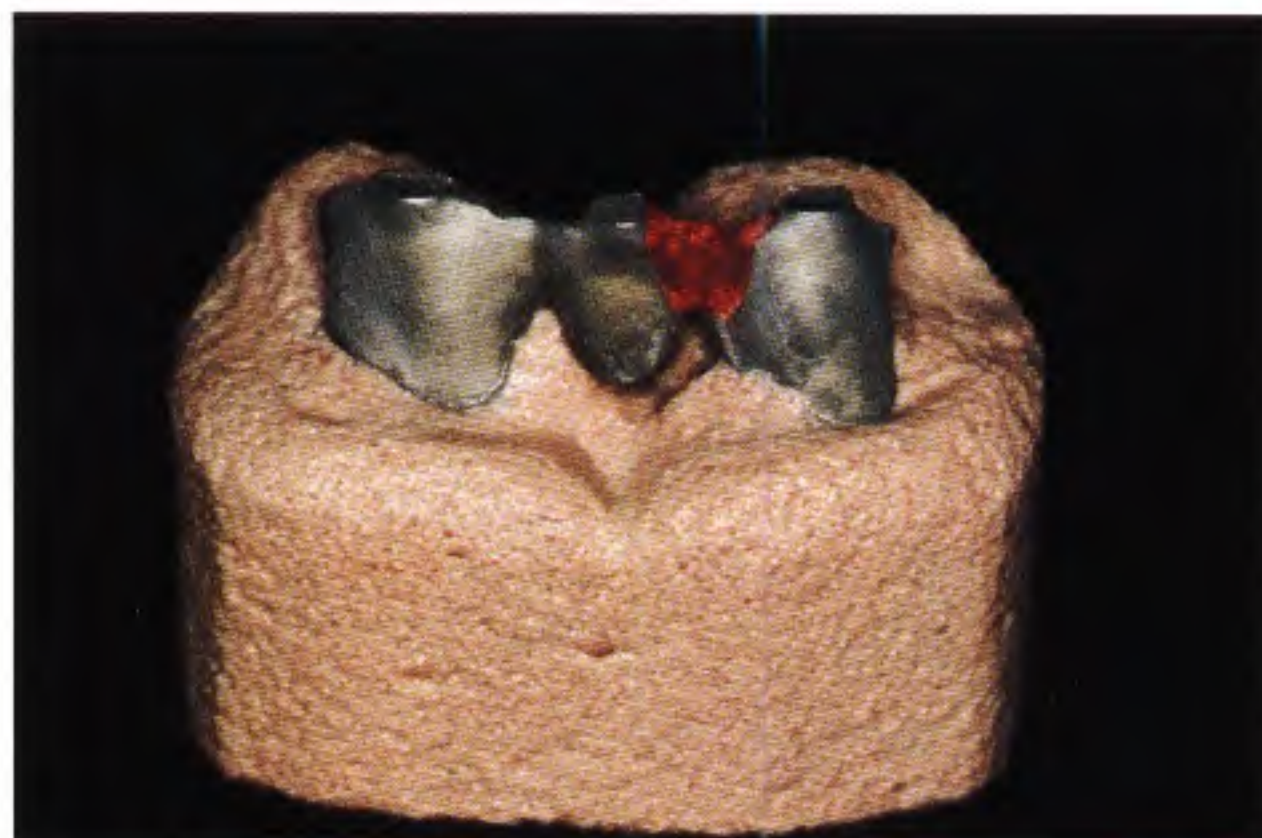


Fig 7-65a Facial view of the trimmed investment patty. Note that all sharp line angles have been removed.



Fig 7-65b Lingual view of trimmed investment patty. The cast 18-gauge holders on the lingual surface have been covered with investment to secure the two components.

Investing

The goal of presoldering is to heat the parent alloy to a temperature high enough to allow the solder to flow into the prepared joint space. All efforts must be made to fully expose the facial, incisal/occlusal, and the lingual surfaces of the fixed partial denture to the heat. If these surfaces are covered with investment they will only absorb the heat and hinder the solder's flow. To invest, mix the soldering investment according to the manufacturer's instructions. Carefully pour the investment in the boxed index or fill each abutment with investment if the units are small and no index was used (Fig 7-63). Place a small patty of investment (about 9 mm high) on a glass slab, and

gently seat the restoration on the patty (Fig 7-64). Only the margins should be covered with the soldering investment. To prevent the casting from settling into the mix, place the patty in a vibration-free area. Allow the investment to bench set for the amount of time specified by the investment manufacturer. To minimize the amount of heat required for soldering, trim the set material to within 6 mm of the castings around the entire periphery and reduce the base to a maximum thickness of 9 mm (Fig 7-65a). Smooth any sharp line angles, and remove the investment under the solder gap to make certain the area is clean (Fig 7-65b). Any residual investment could end up in the solder joint and cause pitting and porosity.

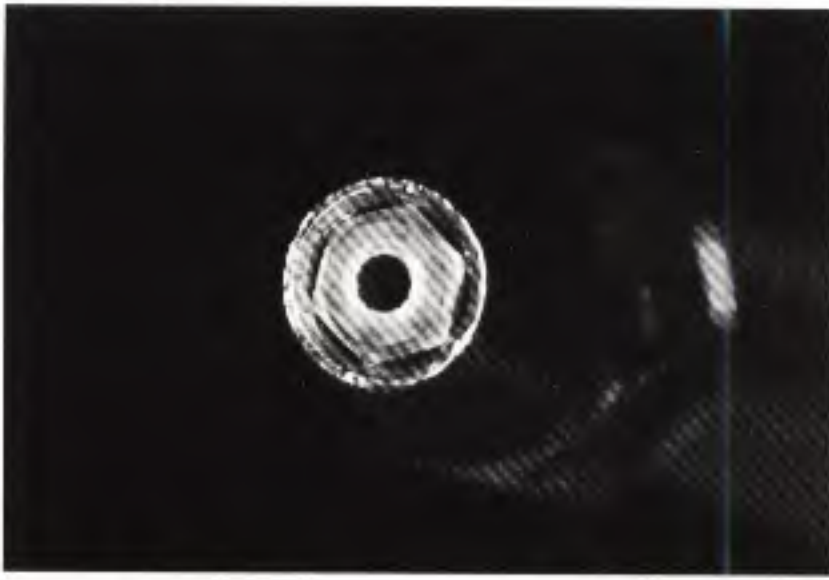


Fig 7-66 Close-up of the single orifice soldering tip on a Magic Wand torch (Williams Dental Co).

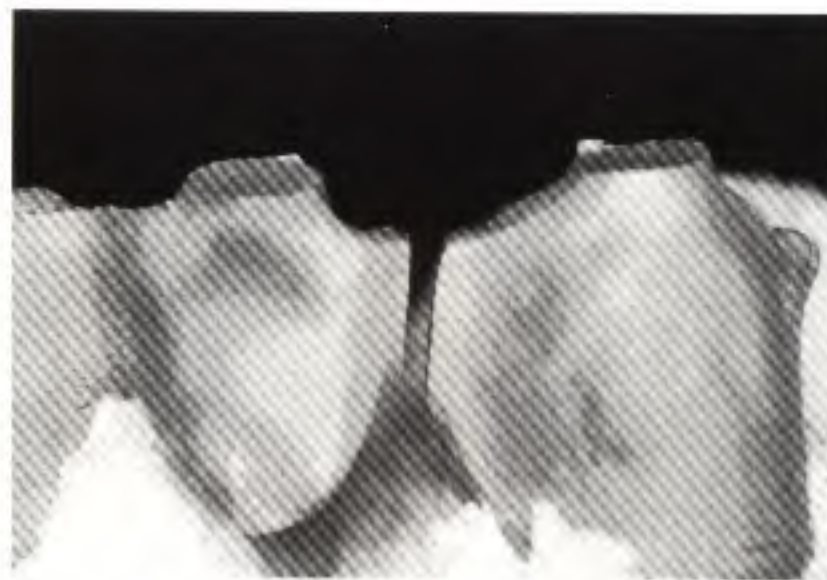


Fig 7-67 Facial view of air-abraded connector area.



Fig 7-68 A fluoride-containing flux for presoldering (High Fusing Bondal Flux, Williams Dental Co). A properly mixed flux should be moist and have a smooth, creamy consistency. Dip the cut solder strip in the pre-solder flux. Simply wipe off any excess so that only a light coating remains.



Fig 7-69a Place a small quantity of flux in the joint itself.



Fig 7-69b The presoldering flux should readily wet the joint.



Fig 7-69c Place the "tadpole" high-fusing solder in the connector area and heat the restoration with the "reducing" zone of the flame.

Soldering

To provide the proper expansion and to burn off the luting agent, preheat the investment patty in a burn-out oven at room temperature. Slowly raise the temperature to 1,200°F over a 30-minute period, and hold the work at this temperature for at least 10 minutes.

While the investment is being heated and the acrylic resin is burning off, assemble the soldering torch, solder, and related equipment. Use a propane/oxygen or natural gas/oxygen mixture as your heat source and select a single-orifice soldering torch tip (Fig 7-66 and see Fig 5-21, A in chapter 5). This type of tip will form a concentrated flame that permits you to control the flow of the solder. As when casting, do not use acetylene or air and natural gas as a heat source. After burnout, remove the work from the furnace. The connector area should be completely free of debris with no signs of residual luting agent

and soldering investment. If debris is evident in the connector area or the alloy is heavily oxidized, allow the substructure to cool and gently air-abrade the joint with aluminum oxide (Fig 7-67).

Some, but not all, ceramic alloys require or benefit from the use of a fluoride-containing flux for pre-soldering. Usually alloys with a high gold content do not readily oxidize so a soldering flux is not necessary. It has also been argued that flux will contaminate the alloy and discolor the porcelain; however, this is not a factor provided the metal is properly finished and cleaned after the soldering procedure (Dykema et al, 1986). If a flux is used, make certain the mix is smooth by adding distilled water and stirring it well. Then dip the solder in the flux and remove any excess (Fig 7-68).

Transfer the work to a tripod heated by a Bunsen burner and covered with metal mesh. The Bunsen

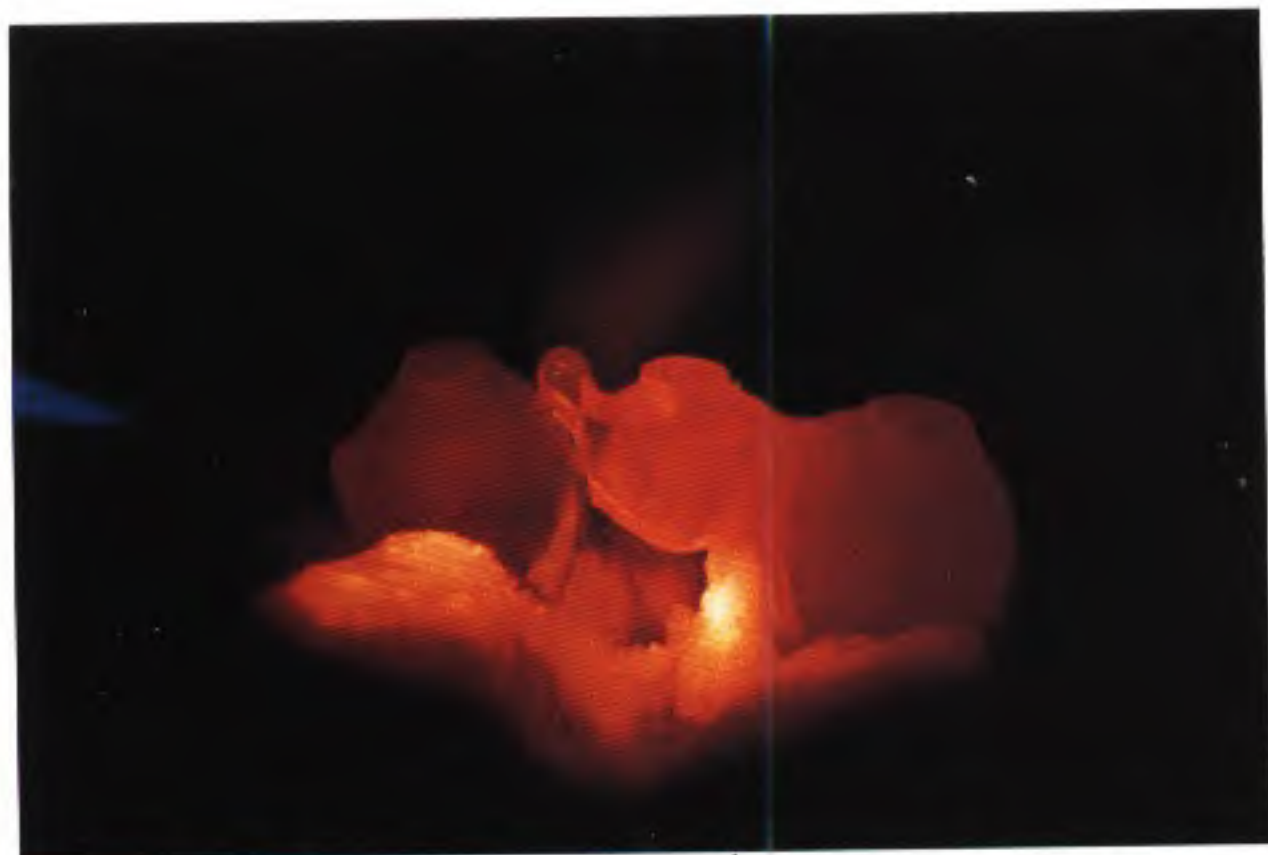


Fig 7-70 As heating continues, the head of the "tadpole" will disappear as the solder slumps and flows into the connector area.



Fig 7-71 Lingual view of air-abraded fixed partial denture after presoldering to confirm the proper fit of the prosthesis. Note that some solder has extended onto the lingual surface of the pontic. This overflow can be removed during finishing.

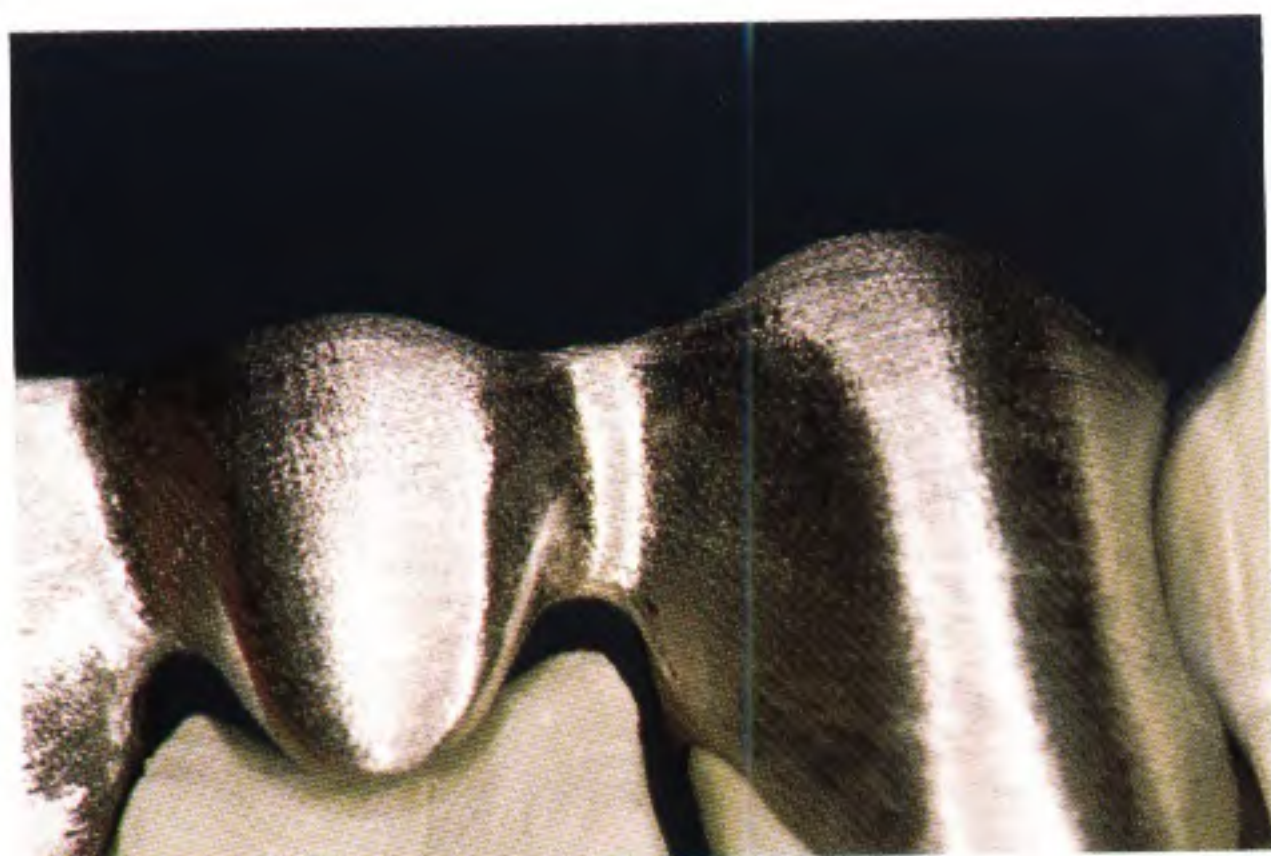


Fig 7-72 Facial view of the soldered connector area of the finished framework. Note that the joint is dense, complete, and virtually indistinguishable from the adjacent parent alloy components.



Fig 7-73 Facial view of air-abraded and cleaned soldered connector area.

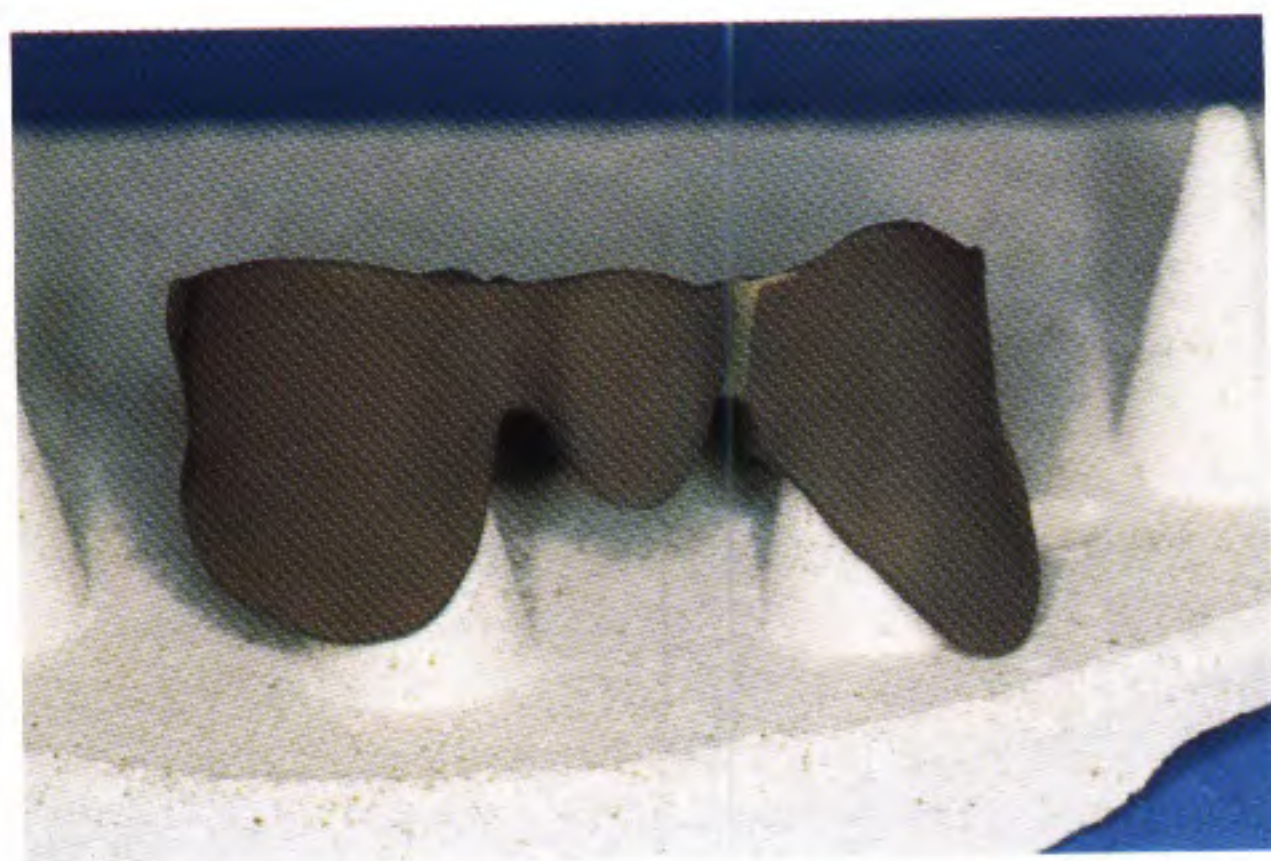


Fig 7-74 Labial view of the framework after oxidation. The oxide layer of Protocol alloy (Williams Dental Co) is uniform in color and appearance.



Fig 7-75 Close-up view of the solder joint after oxidation. The yellow hue of the presolder is readily evident, as is the fact that the solder joint is dense and free of contamination and porosity.

burner will prevent the investment from rapidly losing heat during the soldering procedure. Apply only a small amount of flux to the connector area itself (Figs 7-69a and b) and carefully insert the prepared "tadpole" high-fusing solder (Fig 7-69c).

Solder will always flow toward heat (that is, toward the flame). To take advantage of this behavior, orient the solder opposite the side to which the flame will be held. Normally, you should place the solder toward the facial aspect of the connector area with the flame directed from the lingual surface. Begin the soldering process by heating the entire restoration with the reducing portion of the flame. It is not necessary to heat the investment with the torch. The goal is to heat the parent alloy, not the investment. As the units take on heat, carefully watch the alloy to be sure both sides of the solder gap are the same color. This is your best indication of a uniform temperature. Continue heating the parent alloy until the solder slumps and is pulled or drawn through the solder gap (Fig 7-70). Once the solder has melted and flowed completely, immediately remove the flame and allow the work to cool to room temperature. Remove the fixed partial denture from the investment, air-abrade the metal with 50- μ m aluminum oxide, and clean the prosthesis (Fig 7-71). Check the fit of the prosthesis on the master cast only after it has been thoroughly inspected internally for evidence of debris.

After verifying a proper fit, adjust and finish the porcelain- and nonporcelain-bearing areas of the prosthesis as described previously (Fig 7-72). When the metal finishing is complete, air-abrade the surfaces to receive porcelain with 50- μ m aluminum oxide and even the nonporcelain bearing areas, if you so desire (Fig 7-73). Steam clean or ultrasonically clean the prosthesis in distilled water and you are ready to oxidize the metal in preparation for porcelain.

Oxidizing the fixed partial denture

Despite the fact that the prosthesis was presoldered, the oxidation procedure is performed in the same manner used for a single-unit restoration (see Figs 7-41 and 7-42). Select an appropriate saggar tray to support both retainers, and carefully place the restoration on the muffle stand. Take care to avoid touching the prepared metal substructure to prevent possible contamination of the porcelain-bearing surfaces. Then oxidize the framework under the conditions of time and temperature recommended by the alloy manufacturer.

Inspect the oxidized prosthesis to ensure a uniform oxide was produced that was free of contamination (Fig 7-74). Note the distinct color difference in the presoldered connector areas (Fig 7-75); this is entirely normal.

Summary

Adjusting and finishing a metal ceramic substructure is a relatively simple procedure, but it is also one that must be done correctly if it is to enhance rather than jeopardize the porcelain-metal bond. With fixed partial dentures, presoldering should not be considered an obstacle to obtaining a well-fitting prosthesis. Metal ceramic substructures should be properly oxidized to prepare the metal surface for porcelain.

Now that you know how to adjust and finish a single-unit substructure as well as presolder a fixed partial denture, you are ready to proceed to chapter 8 for a presentation on the techniques for applying porcelain to these substructures.

Applying Porcelain to the Metal Substructure

The application of dental porcelain to the metal substructure is perhaps the single most demanding procedure in the fabrication of a metal ceramic restoration. As a rule, the skills needed for this particular process require the most effort to perfect. Moreover, the instruments and techniques used for porcelain buildups are so numerous and varied it would be impossible to include a comprehensive review of each and every one. So the techniques presented in this chapter depict a basic approach to porcelain application. Nonetheless, they can be used as a springboard for the developing ceramist. Certainly once the fundamentals are mastered the potential for improvement and incorporating more advanced techniques is limitless. Initially, however, it is essential to develop basic skills founded on sound principles for success in the fabrication of a functional and esthetically pleasing restoration.

Instruments and equipment

The armamentarium for applying porcelain as described in this chapter is really quite simple (Figs 8-1 and 8-2) and at the very least should include some of the following items.

Brushes

A variety of brush sizes and styles are available in porcelain instrument kits, the most important of which are the brushes used for building or stacking porcelain. A very high-quality sable brush is recommended. The size range varies from a no. 4 to a no. 8, reflecting the personal preference of the ceramist. But use only well-made brushes and avoid less expensive substitutes. Sable brushes are the standard because they permit easy manipulation of the porcelain. Their

added cost is more than paid for through improved working efficiency and durability.

There is a simple test you can use to identify a high-quality brush. Simply moisten the bristles thoroughly and then remove the moisture either by shaking the brush or pulling the bristles across a tissue. If the brush is of a high quality, the bristles will readily form a sharp tip or "point." This point facilitates picking up the porcelain from the glass slab and improves control during placement of the porcelain on the crown buildup. Worn or inferior-quality brushes will not "point" as described. A technique for "pointing" a brush will be presented later.

Another frequently used instrument is a large no. 10 brush, often referred to as a whipping brush (see Fig 8-2). Its large surface area and soft bristles make it useful for smoothing the porcelain buildup or contouring, condensing, and even removing excess porcelain.

A basic instrument kit should also include flat brushes with relatively stiff bristles. These large- and small-sized brushes should be kept dry, because they are used exclusively to remove porcelain particles from nonporcelain-bearing areas and from inside the substructure prior to firing (Fig 8-3). Finally, very small no. 0 to no. 000 sable brushes are required for the placement of stains or small increments of porcelain (see Fig 8-1). These brushes are useful anywhere maximum control is necessary.

Carving instruments

Porcelain carving instruments, designed for shaping and carving porcelain buildups, are offered in diverse shapes and sizes. Many of these instruments are rigid and some have at least one serrated end. As a group, carving instruments serve two principal functions. First, those with a serrated handle can be used to condense wet porcelain. Second, other instru-

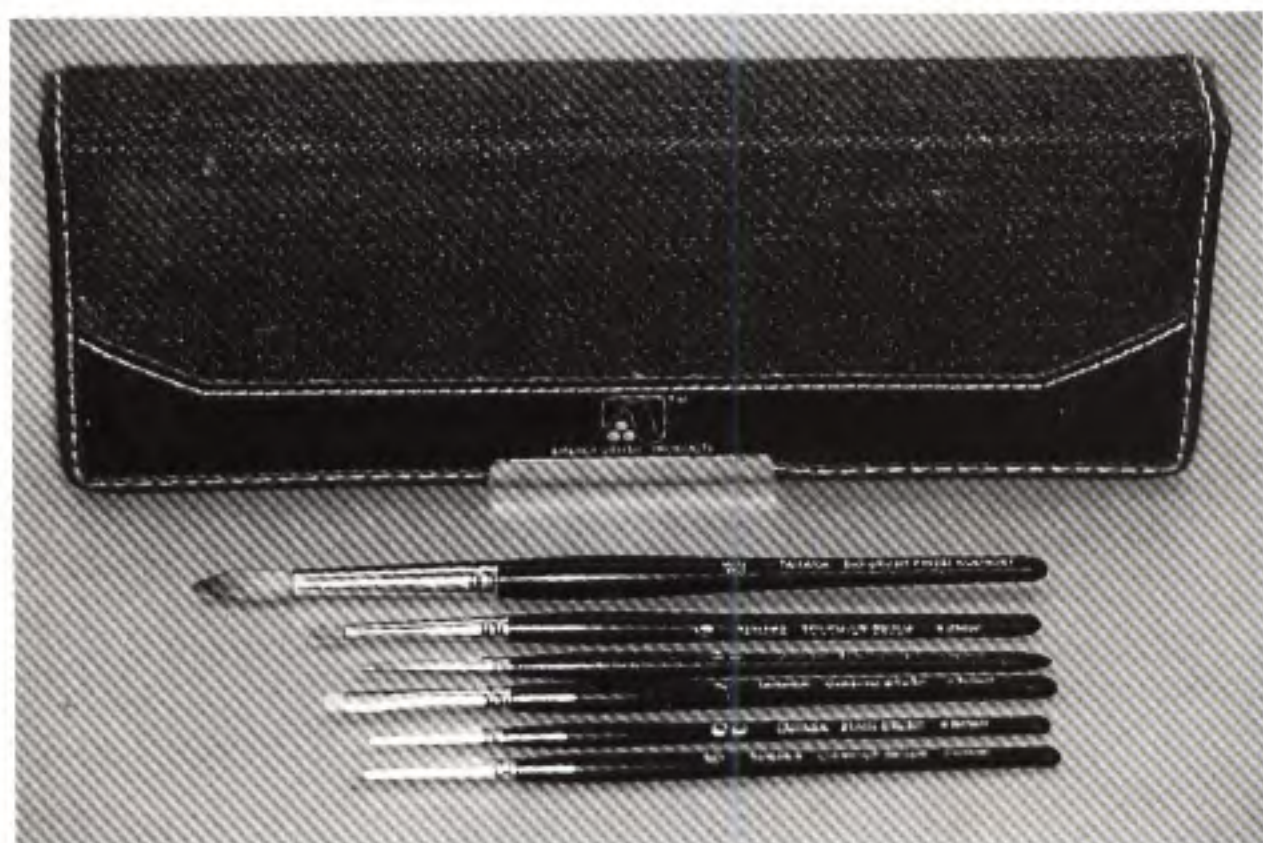


Fig 8-1 An assortment of brushes from a Tanaka porcelain kit (Tanaka Dental) in a variety of shapes and sizes. The large brush is used in a porcelain buildup technique and the smaller brushes (eg, no. 00) are designed for staining and glazing or removing porcelain from exposed metal.

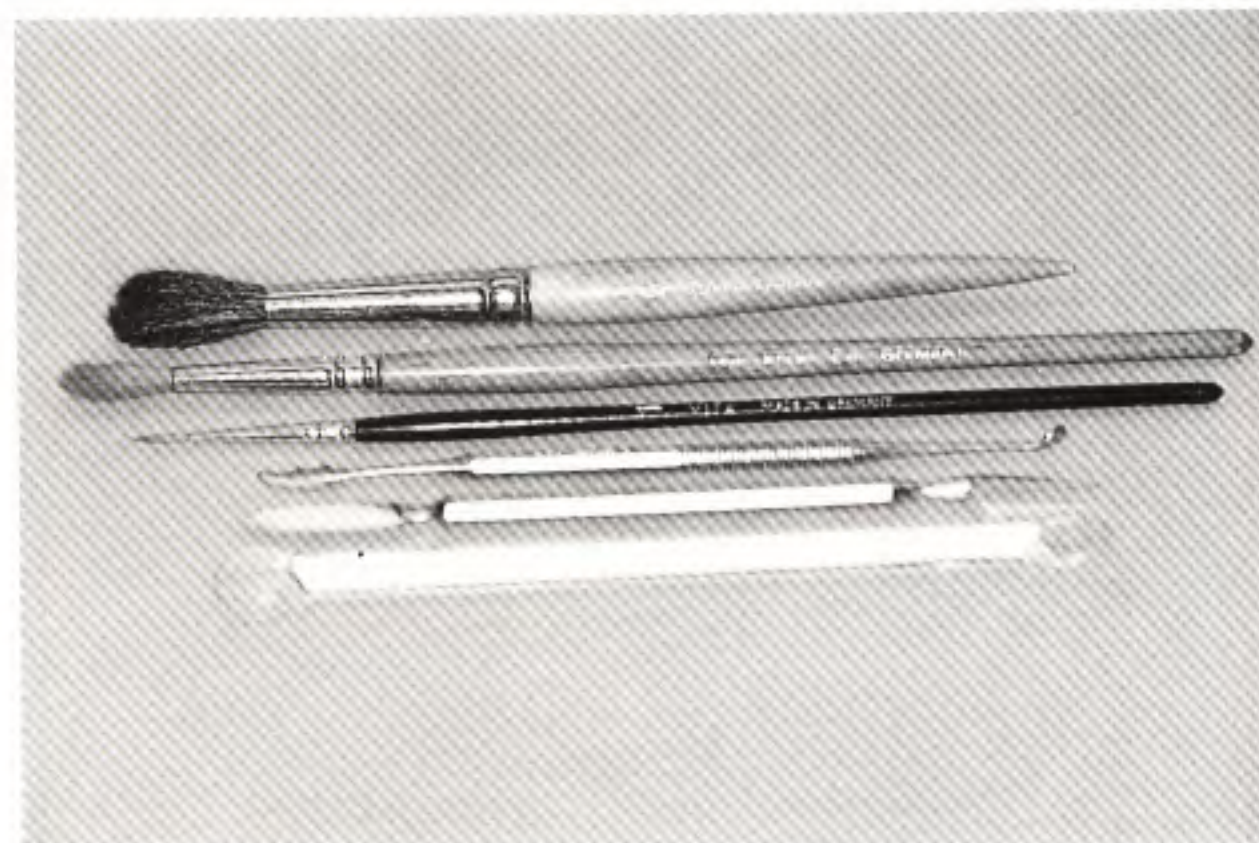


Fig 8-2 A variety of instruments from a Vita porcelain kit (Vident) includes a large no. 10 whipping brush, no. 6 and no. 1 brushes for porcelain application, metal carving instruments, and a glass mixing rod.

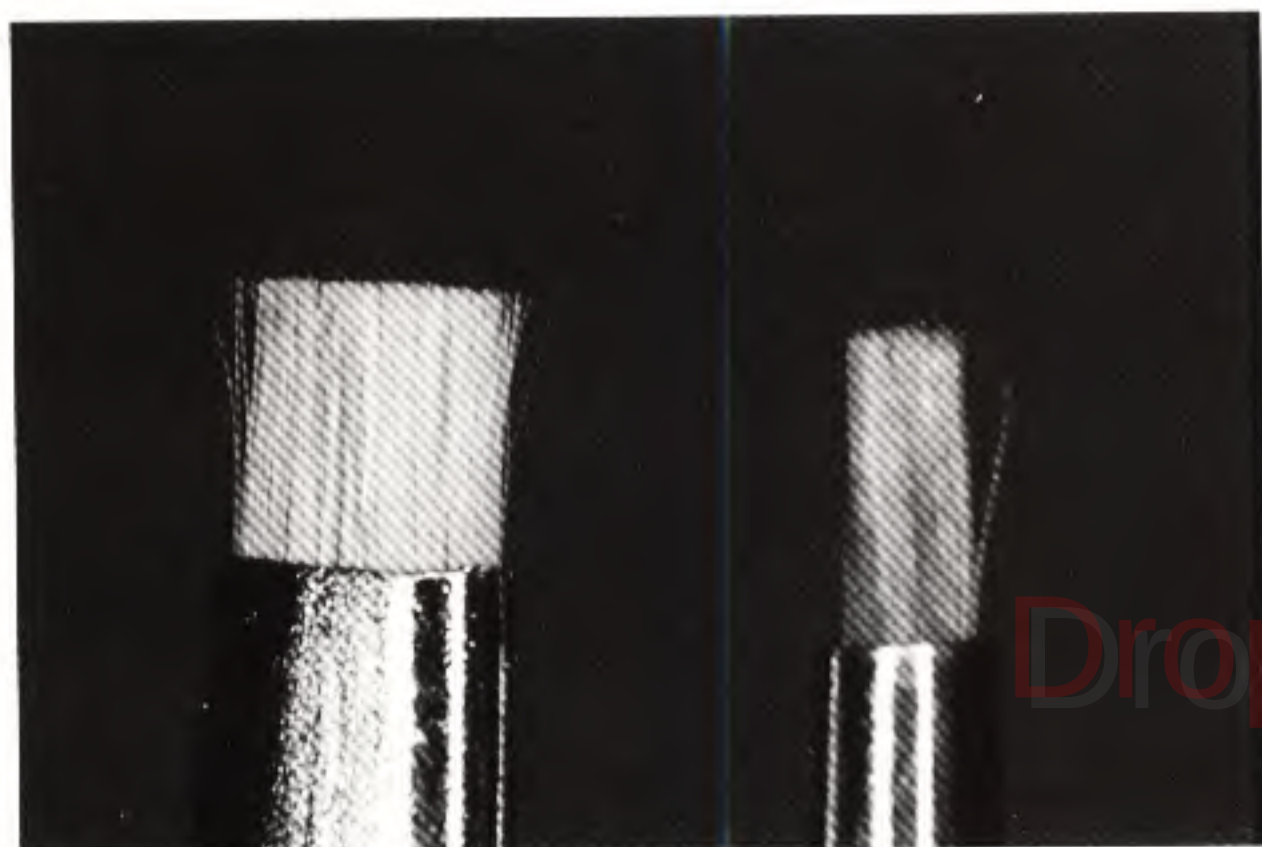


Fig 8-3 Tanaka large and small stiff-bristle brushes used to remove dry porcelain from nonporcelain-bearing areas such as metal margins, porcelain-metal junctions, and the intaglio (inside) surface of the metal substructure.



Fig 8-4 Belle de St Claire carving instruments for stacking and shaping the porcelain buildup. Note the straight cutting edge on the flexible blade of the knife (*bottom*).



Fig 8-5 A glass rod (*left*) is better suited for mixing porcelain than a metal instrument (*right*), because the porcelain can abrade the metal instrument, contaminate the opaque mix, and discolor the fired porcelain. These are actually two mixes of the same shade of opaque porcelain but the mixture on the right has a lower value due to metal contamination.

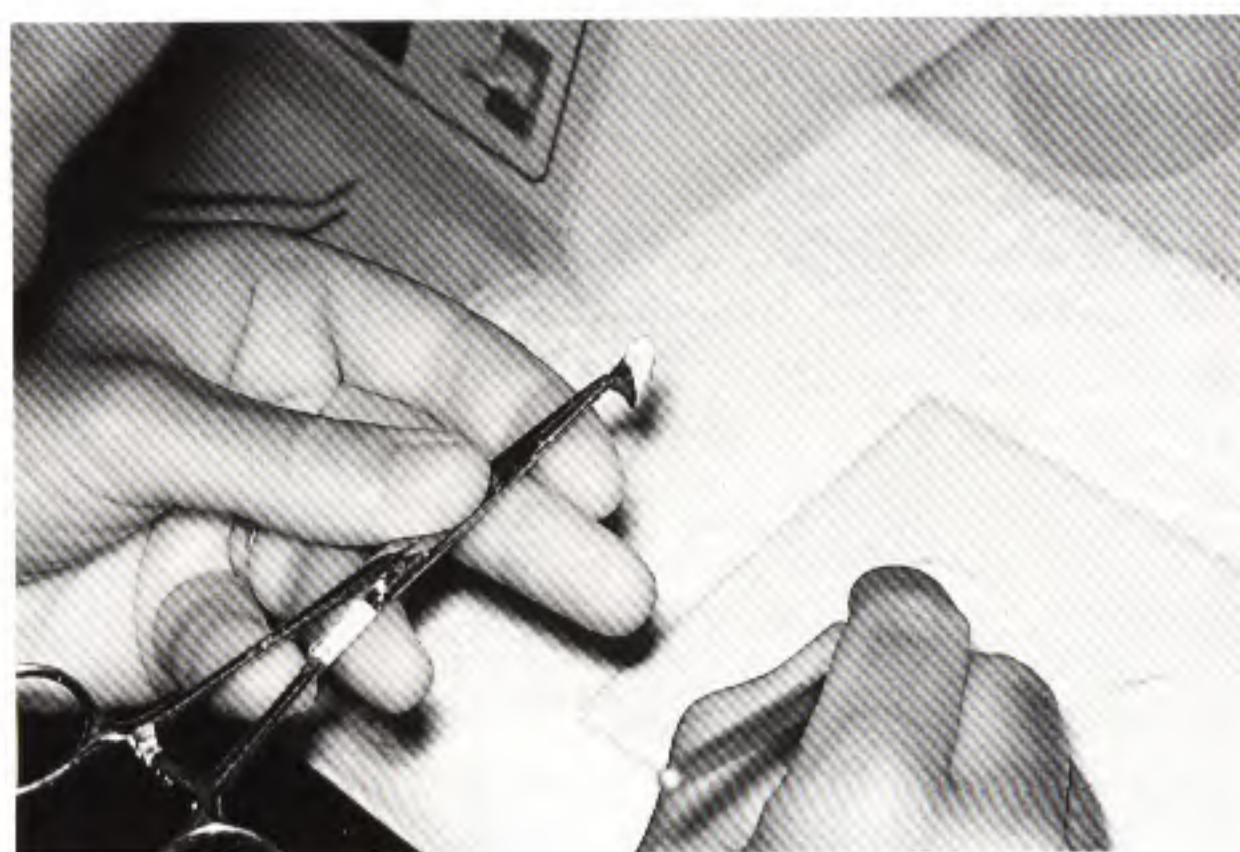


Fig 8-6 A straight or curved hemostat attached to the cast 18-gauge handle on the metal substructure improves access to all areas of the restoration during the fabrication process.

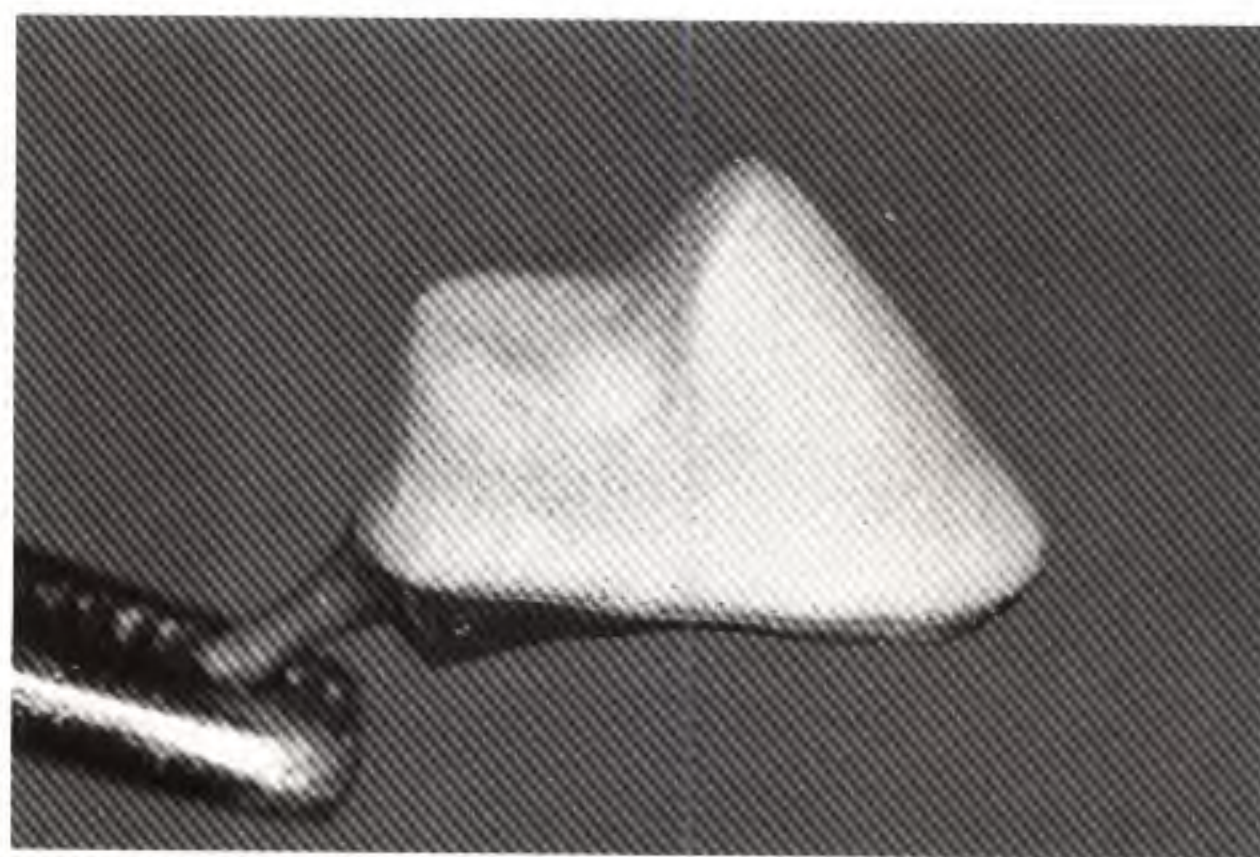


Fig 8-7 The cast metal handle is particularly useful for copings with minimal exposed metal because you avoid possible damage to delicate metal margins.

ments with blades (Fig 8-4), as well as the small discoid carver, can be used to build (stack) porcelain, shape the buildup, and carve the porcelain as will be demonstrated in the technique section.

Spatula

Some ceramists prefer to include a small, flexible, metal spatula in their armamentarium to dispense and mix porcelain. However, exercise caution when using any metal instrument to mix dental porcelain; as with all ceramic materials, dental porcelain can easily abrade metallic surfaces, particularly if appreciable pressure is applied during mixing. Any small metal fragments generated during mixing can then be introduced into the wet porcelain as contaminants. This metal debris can dramatically discolor the mix (Fig 8-5) as well as the fired porcelain restoration. With careful use, however, the metal mixing spatula need not be abraded. But for added safety, a glass mixing rod is often substituted for the metal spatula to avoid this problem altogether.

Razor knives

Another necessity in the basic set of instruments is some type of razor knife, equipped with a thin, flexible blade for carving the porcelain buildup (see Fig 8-4). Thicker knives or scalpel blades are not considered suitable alternatives for this particular instrument because of their greater bulk and accompanying lack of flexibility.

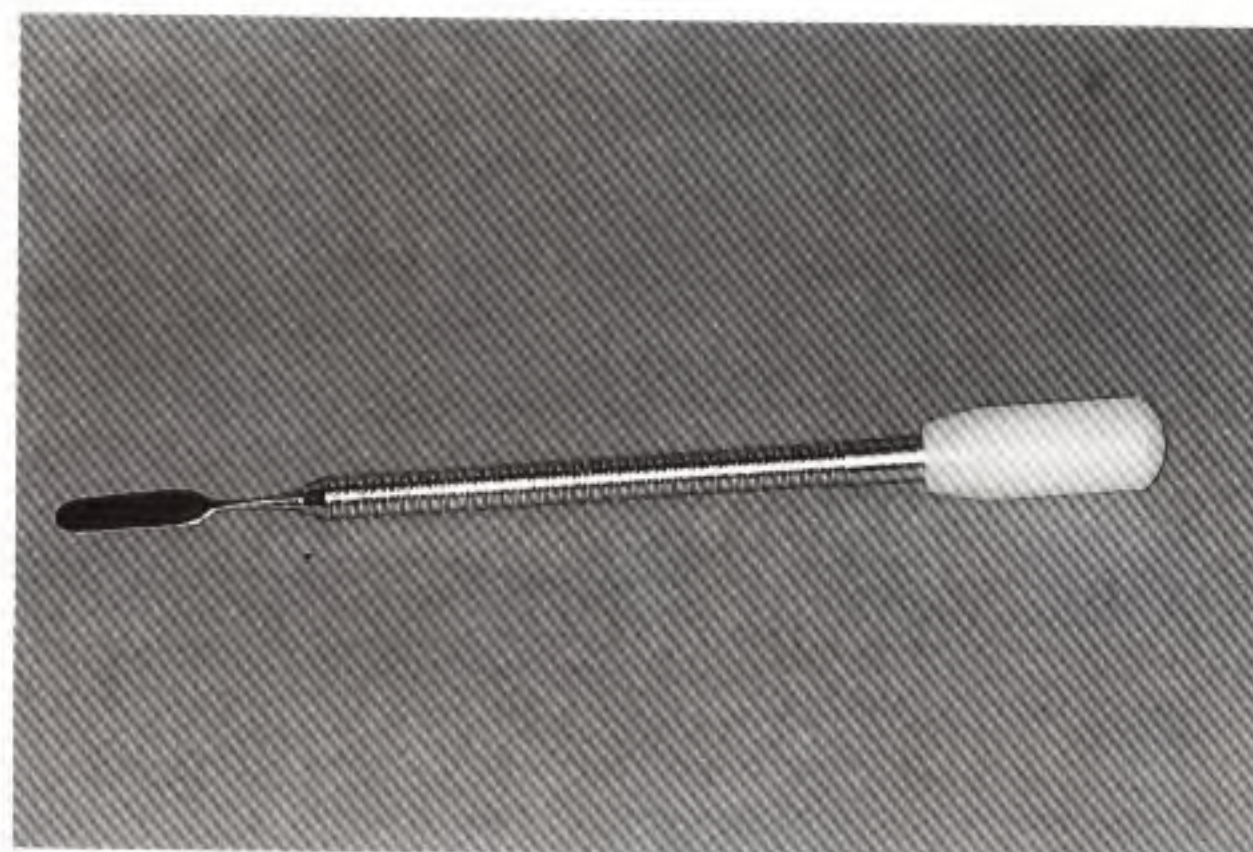


Fig 8-8 A mallet can be used to lightly tap the working cast and condense the porcelain buildup in a very controlled manner.

Hemostat

A small, straight or curved hemostat is needed to hold the work during the opaquing process and at certain times during porcelain additions and condensation (Fig 8-6). Hemostats can be modified to hold the metal substructure securely without damaging the metal margins. However, an 18-gauge handle added to the lingual collar provides a convenient, safe, yet secure grip for removing the restoration from the working cast and holding it during condensation, especially for restorations with minimal metal collars (Fig 8-7). Generally, this handle can be shortened after the crown has been fabricated but left intact during the try-in procedure to enable the dentist to remove the restoration from the patient's mouth. This modification is particularly convenient during intraoral characterization with surface stains. Obviously, the handle is removed and the metal is polished after glazing but before final cementation.

Condensing mallet or instrument

This is a useful addition to your list of porcelain instruments (Fig 8-8). Lightly tapping the working cast while the restoration is still on it is yet another way to condense the porcelain buildup. The value of such a procedure is discussed in greater depth in the explanation of the porcelain buildup technique.

Glass or ceramic mixing slab

Finally, either a glass slab, ceramic tile, or ceramic tray can serve as a palate for mixing and storing the

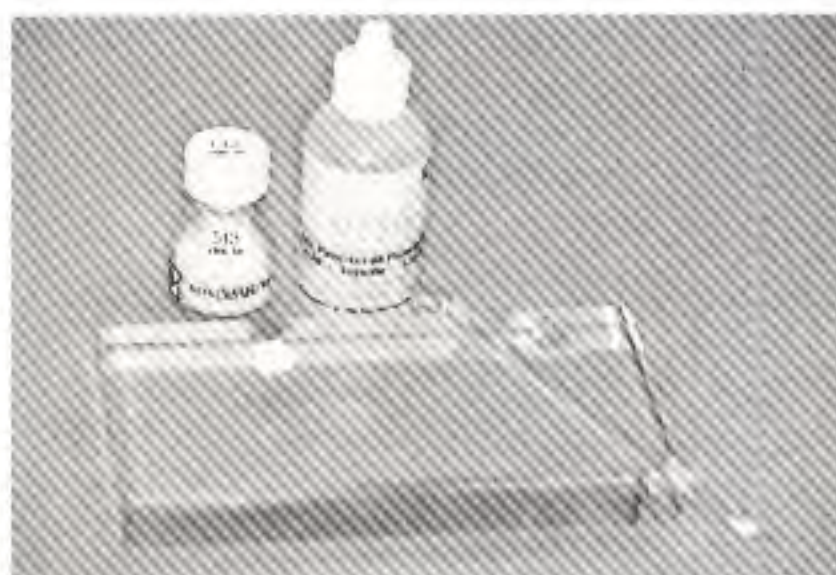


Fig 8-9a A glass slab can be used as a palette for mixing and storing dental porcelain. The glass rod can be used to dispense and mix opaque porcelain with the opaque liquid (Vita VMK 68 porcelain, Vident).



Fig 8-9b A large ceramic slab is recommended for the buildup procedure because you have more working area to accommodate mixes of dentin, enamel, translucent porcelain, and various modifiers (Vita VMK 68 porcelain from Vident is shown).



Fig 8-10 A Tanaka ceramic tray has an air-tight lid and individual recessed areas kept moist by wicks drawing liquid from a reservoir below the tray.

porcelain during the buildup procedure. Initially, a small mixing slab will suffice (Fig 8-9a). As modifiers are added and more complex buildups are attempted, a larger working surface will be required to accommodate all the different porcelain mixtures (Fig 8-9b). Generally, when the powders mixed on a glass slab or ceramic tile are allowed to dry out, these mixes often are subsequently discarded. To avoid such a waste of material, several manufacturers offer special ceramic trays designed to keep the porcelain powders moist even when not in use. These trays have air-tight lids to prevent evaporation. Liquid is stored in a reservoir and a wick draws moisture to the individual porcelain mixtures (Fig 8-10).

The porcelain furnace

A porcelain furnace, or oven, is the single most expensive piece of equipment required for the production of metal ceramic restorations. At least three types of furnaces are available: manual, automatic, and programmable. They are offered by many sources in a variety of styles (Figs 8-11a to d).

Invariably, you will find that there are certain features common to almost all brands and types of porcelain furnaces that certainly should be present on any you might consider purchasing. For example, modern low-fusing porcelains are fired under vacuum rather than at atmospheric pressure. Consequently, all furnaces are equipped so the firing chamber or muffle can be sealed and, with the aid of a pump, establish and maintain a vacuum during the firing cycle. In the event the vacuum does not reach an adequate level, or if the firing chamber does not properly seal, resulting in a loss of vacuum during the

firing cycle, the quality of the fired porcelain will be compromised. In fact, there can be a significant loss of translucency and vitality in the fired porcelain. Ideally, the vacuum pumps should reduce the atmospheric pressure in the muffle to 700 to 740 mm of mercury (Hg).

A porcelain furnace should also have an adjustable rate of climb from the low entry temperature up to the high firing temperature. The rates of temperature ascent (rate of rise) and cooling should be adjusted for different porcelain-metal combinations as well as for different functions. Manufacturers generally will recommend a rate of rise for their particular porcelain system. However, this rate of heating and cooling may vary with different brands of porcelain and types of casting alloys.

Most furnaces can also be set to hold the work at a temperature for a specified length of time as determined on a case-by-case basis. This feature is used when firing certain porcelain materials that require a hold time at a specified firing temperature. The ability to maintain work at a high temperature for a prescribed interval is also necessary during the oxidation of the metal substructure and when glazing the finished restoration.

Whether manual, automatic, or programmable, porcelain furnaces can be divided into two basic categories depending on the manner of entry into the muffle. Some furnaces are designed so the work is inserted from front to back (horizontally) and are referred to as front-loading furnaces (Figs 8-11a and 8-12). The front-loading muffles tend to be hotter near the back of the muffle and cooler near the door. As a result, there may be observed differences in the appearance of porcelain fired in the back of the firing chamber compared to that fired in the front. The variation in the appearance of the fired porcelain may

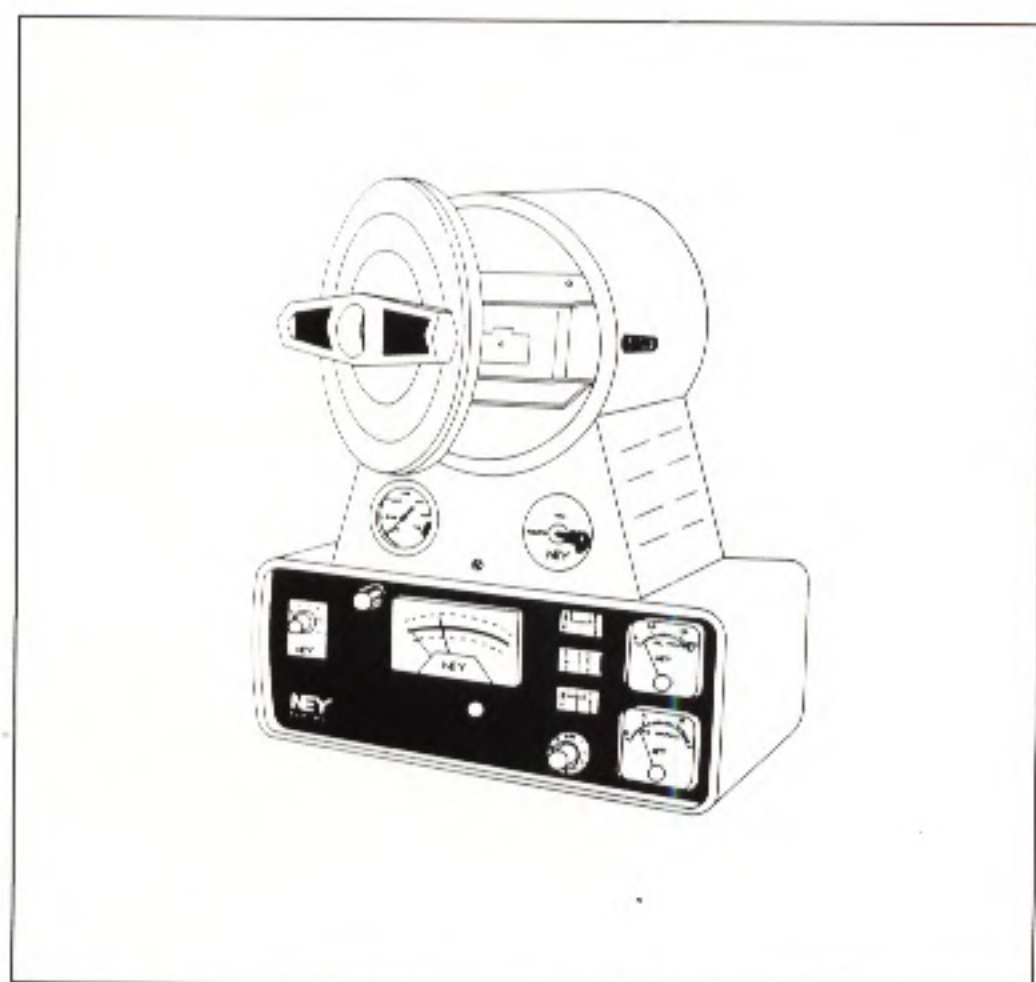


Fig 8-11a A Ney Mark III manual porcelain furnace (J. M. Ney Co).

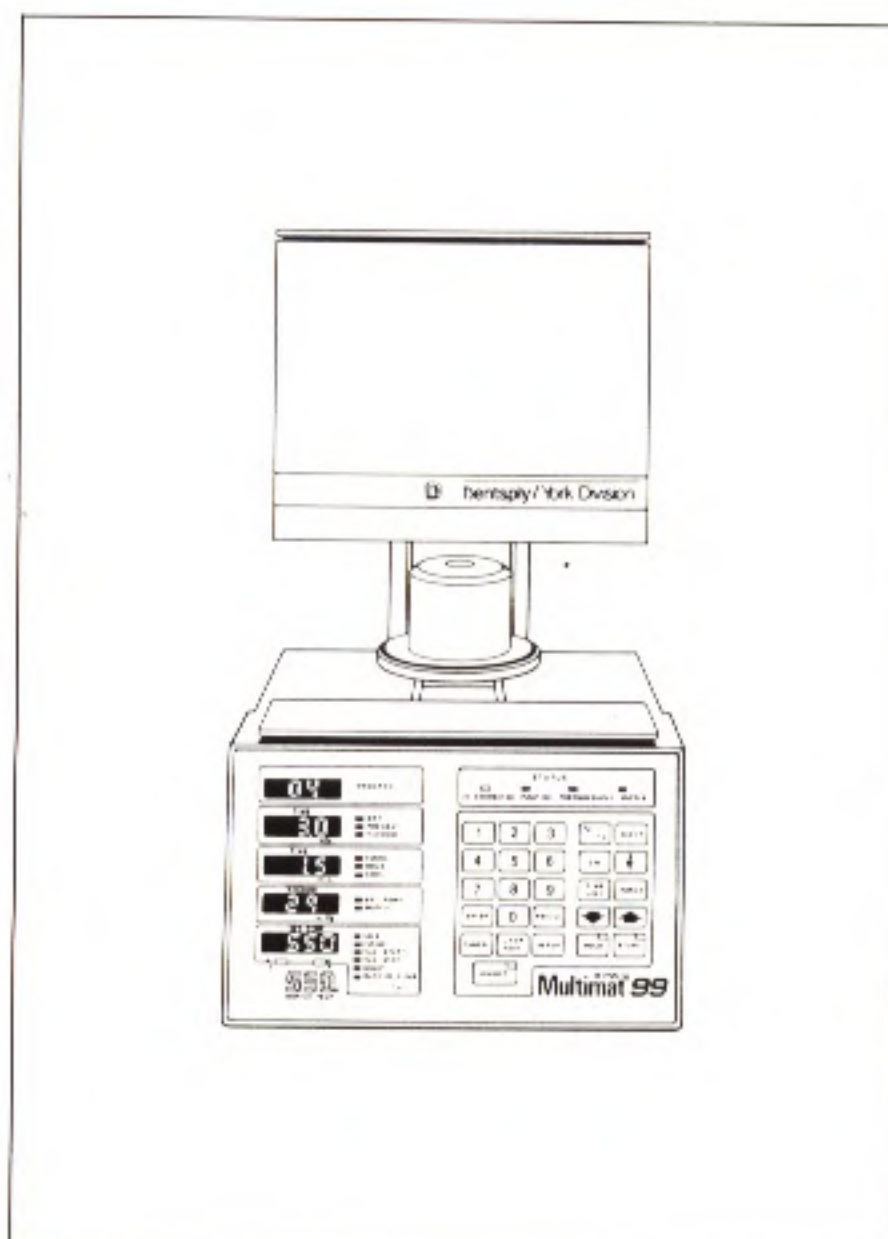


Fig 8-11b A Multimat 99 programmable porcelain furnace (Dentsply International).

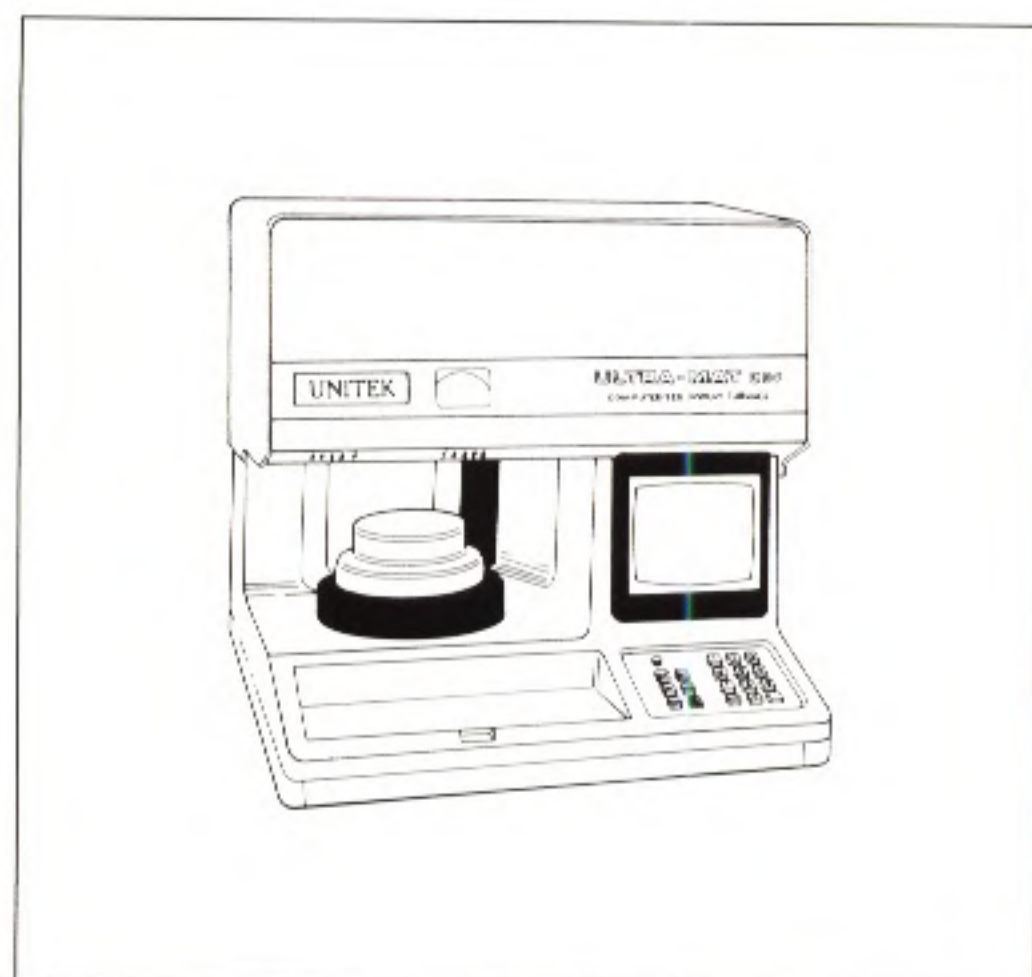


Fig 8-11c An Ultra-Mat CDF programmable porcelain furnace (3M/Unitek).

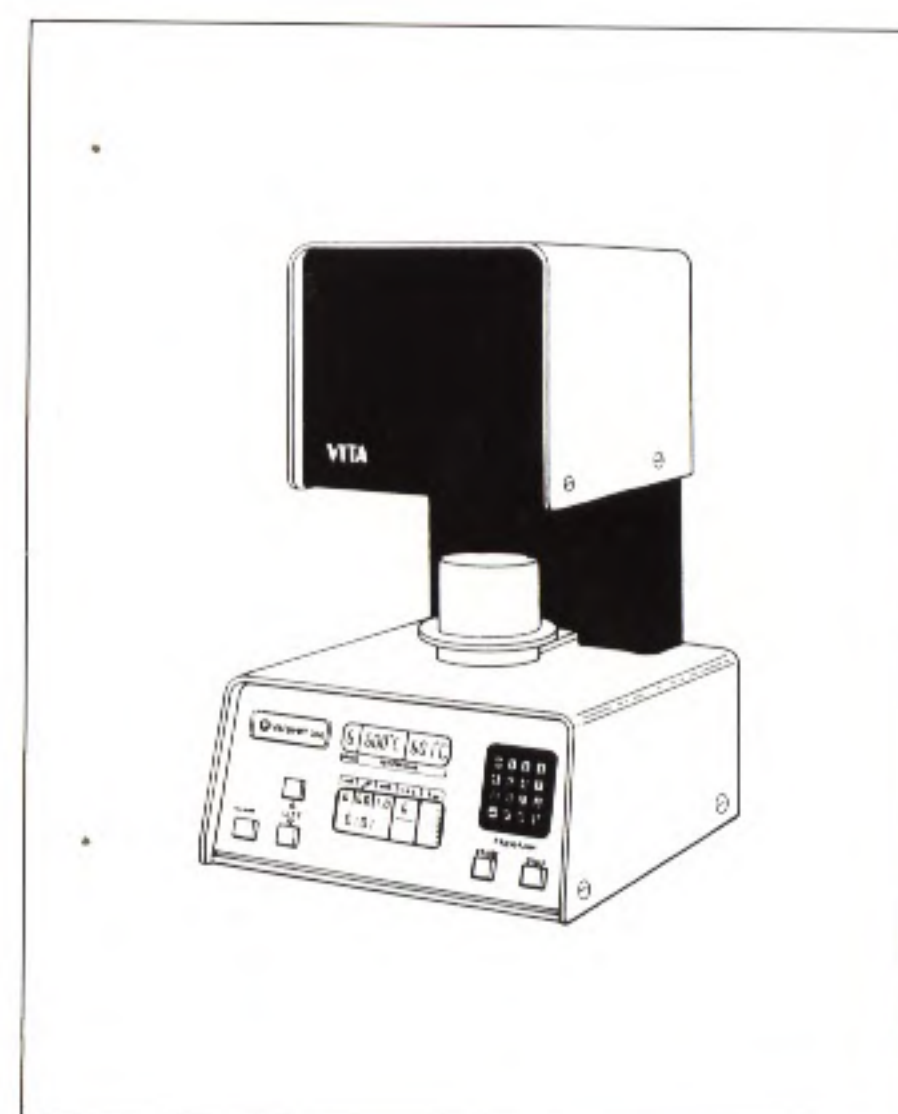


Fig 8-11d A Vita Vacumat 200 programmable porcelain furnace (Vident).



Fig 8-12 A front-loading porcelain furnace with a horizontal muffle (Ney Mark III).

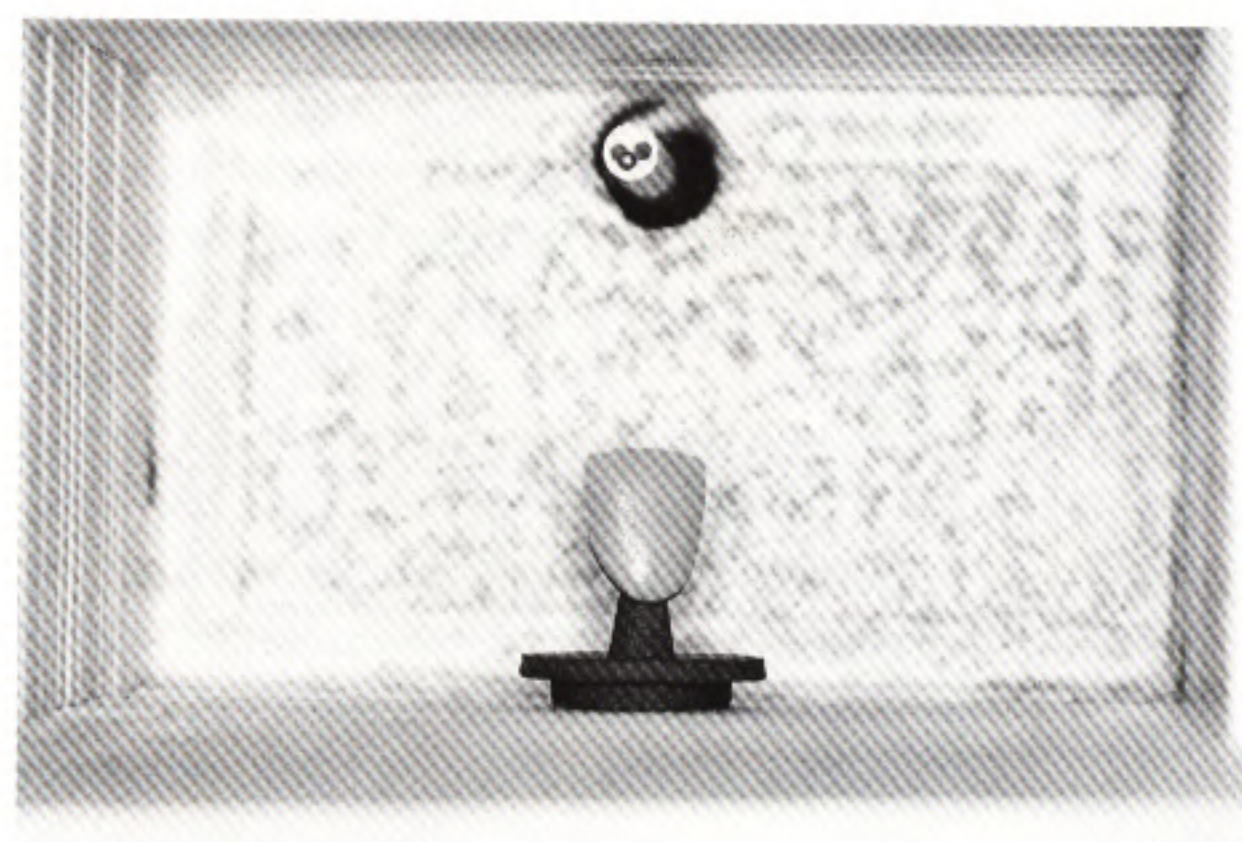


Fig 8-13 A restoration should be positioned directly under the thermocouple to ensure consistent and uniform heating.

be particularly noticeable during the metal oxidation cycle. Those substructures oxidized in the rear-most portion of the muffle will have a significantly heavier oxide layer than those heated near the door. As long as you are aware of this difference and routinely position work as far to the back as possible and directly under the thermocouple (Fig 8-13), this potential problem should be a matter of little concern.

Furnaces in the second category have a vertical entry into the muffle (see Figs 8-11b to d). With the vertical-loading design, the muffle platform, with the restoration placed in its center, is raised up into the furnace muffle (Fig 8-14). The vertical loading design reportedly provides a more uniform temperature distribution throughout the muffle and allows the work to be completely surrounded by the heating elements.

Porcelain condensation

Before discussing the actual porcelain application process, there is one procedure that warrants some explanation—porcelain condensation. The process of condensing dental porcelain actually refers to any procedure that results in the unfired porcelain particles being tightly packed (condensed) onto themselves. As the particles move closer together, the air and moisture previously occupying the space between the individual particles move to the surface of the buildup. Any liquid or air that remains trapped in the unfired porcelain will form voids (porosities) in the fired ceramic.

The presence of porosity in fired porcelain weakens the restoration and impairs its esthetic qualities. Voids occupy space that could have been filled by porcelain and result in a loss of both color and translucency. It is easy to appreciate how the presence of voids throughout the porcelain could weaken the material. But how do voids adversely affect the optical qualities of a ceramic? As light passes through any translucent material—even dental porcelain—and strikes an air bubble, the light scatters in all directions rather than passing completely through that area. The visual impact of many small voids scattering light is that the restoration takes on a cloudy (opaque) rather than a translucent appearance. More voids and greater opacification translate into a perceived loss of color.

An advantage of well-condensed porcelain is said to be a reduction in the amount of firing shrinkage. All porcelains shrink when sintered (fired) due to the loss of moisture and the increase in density of the porcelain particles as they become molten and fuse together (vitrify). It stands to reason that condensation increases the density of the unfired material by moving the particles closer together initially. Increased

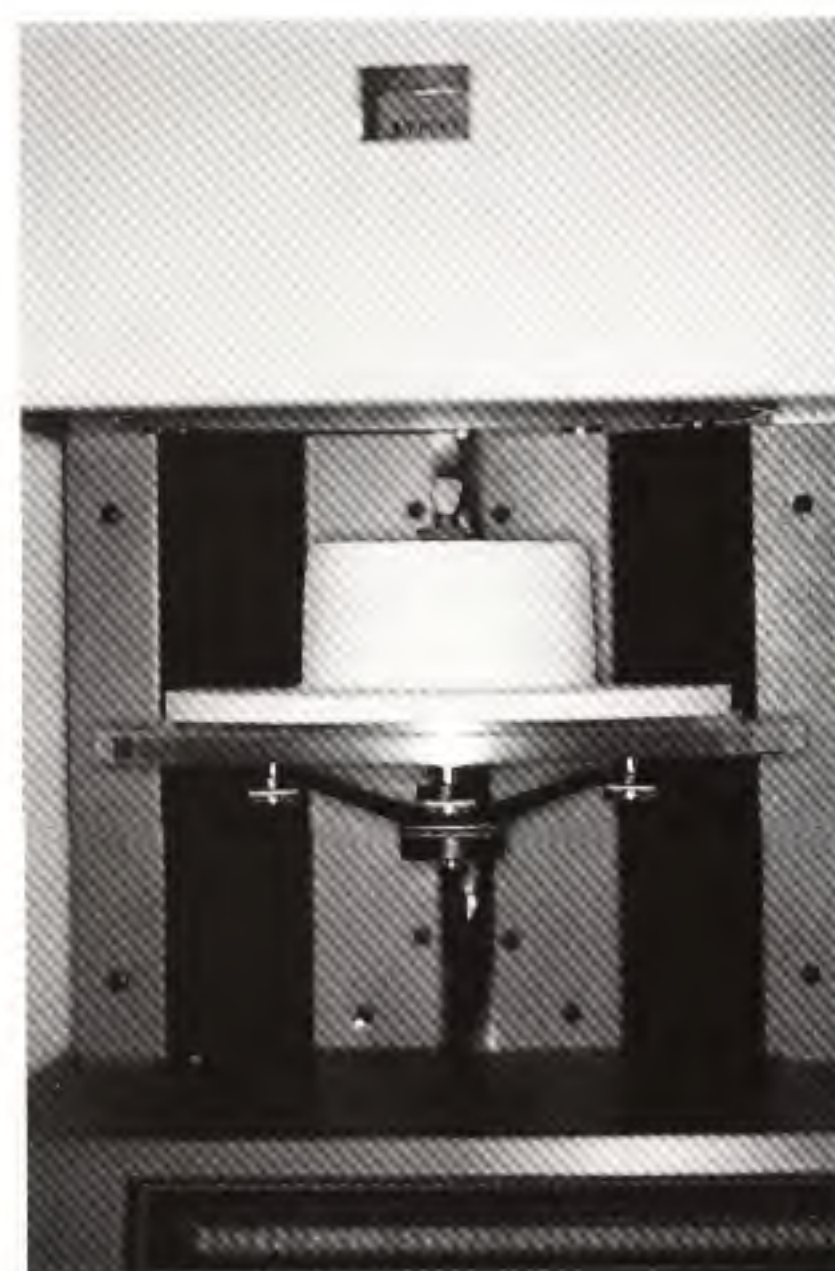


Fig 8-14 With a vertical-loading porcelain furnace, work is placed on the center of the ceramic platform and automatically raised into the vertical muffle (Jelenko's Admiral furnace is shown).

density in unfired buildup results in less shrinkage during firing.

Finally, the porcelain-to-metal bond is maximized with thorough condensation of the opaque porcelain. Obviously, the metal substructure is more completely wetted as the porcelain is applied and vibrated (condensed).

At least five different methods for porcelain condensation have been proposed and include capillary action, vibration, spatulation, whipping, and dry powder addition (Naylor, 1986).

Capillary action

The technique of blotting a wet buildup with absorbent paper (eg, facial tissue, gauze, or blotting paper) uses surface tension (capillary action) to withdraw the liquid and pack the porcelain particles together (Phillips, 1982). Ordinarily this procedure is performed in conjunction with one or more of the other condensation techniques. Capillary action or surface tension alone does not remove all the available liquid. The cyclic action of vibration, or whipping, followed by blotting is repeated until free liquid can no longer be forced to the surface of the porcelain. Usually a delicate touch is all that is required to initiate this mechanism. An overly aggressive technique could dislodge the porcelain buildup from the underlying

metal substructure or shift the stacked porcelain from its intended position.

Vibration

The easiest and simplest form of vibration is created by passing a serrated instrument over the neck of a hemostat in which the restoration is held (Muia, 1982), or by slightly tapping the hemostat neck. Alternatively, if the restoration is left on the cast, the entire cast can be tapped or vibrated. Whether the restoration is vibrated on a hemostat or a cast, the end result of the vibration will be to force the excess water to the porcelain surface. At that point, blotting material can be placed on the wet buildup and capillary action will condense the porcelain. There are several devices on the market designed to provide mechanical vibration, such as vibrating brushes, spatulas, and ultrasonic condensers. For the beginner, ultrasonic equipment should be limited to the final stages of condensation, reserving preliminary condensation for some other method, such as gentle tapping. Without this gentle initial condensation, the delicate buildup will undoubtedly slump or the layer of porcelain will run together.

Surface tension is the force that causes all liquids to contract to their smallest possible surface area. This property accounts for the transformation of water droplets into a spherical mass. In a wet bulk of porcelain, this force helps to pack the particles more tightly during vibration and blotting. When blotting alone is used, all the available moisture near the surface is drawn off, yet some action is needed to bring additional moisture to the surface. Vibration is a means to mechanically draw additional moisture to the surface, where it can then be removed by blotting with tissue.

Spatulation

With this form of condensation, a spatula or porcelain carver is used to apply, then rub (or pat) the porcelain buildup to force the liquid to the surface (Phillips, 1982; Muia, 1982). This technique brings with it a greater likelihood of porcelain dislodgement, particularly if too much pressure is used and especially with the initial buildup. An undetected dislodgement could then result in porcelain cracks (Muia, 1982).

Whipping

This method may actually be nothing more than a variation of the vibration technique. As the porcelain is built up, a no. 10 sable brush is rapidly moved over

the porcelain surface with a whipping motion. The whipping action brings the liquid to the outside surface for blotting.

Dry powder addition

This approach to porcelain condensation may be less widely known and the least used of the available condensation methods. The technique, also referred to as the brush application method, requires that dry porcelain powder be sprinkled on an area of wet porcelain (McLean, 1979), using the existing liquid to moisten the powder additions. Obviously, estimating the correct amount of powder to add and then placing that powder in an appropriate position on the restoration is not without its problems. For the beginner, the technique certainly appears to be more time-consuming.

Ample controversy exists over which condensation method is the most effective. Nonetheless, it is universally recognized that the inclusion of porosities in fired porcelain is something to be avoided or eliminated if at all possible. The first and possibly most critical step in creating a dense, void-free buildup is proper mixing and subsequent handling of the wet porcelain. Where appropriate, several of these methods of porcelain condensation will be illustrated in the technique sections that follow.

Opaquing the metal substructure

At this point it is assumed that the metal has been properly finished, cleaned, and oxidized. If this is the case, the areas of the substructure that will be veneered with porcelain must not be touched and should be protected from dust, oils from the skin, and any other forms of contamination. When the ceramist is satisfied that proper procedures have been followed and that the metal is ready for veneering, the first material to be applied is the opaque porcelain.

Functions of the opaque porcelain

As mentioned in chapter 2, opaque porcelain serves three functions critical to the success of the completed restoration: (1) it establishes the porcelain-to-metal bond, (2) it masks the color of the metal substructure, and (3) it initiates the development of the selected shade. The thickness of opaque porcelain required to adequately mask the metal oxide will vary

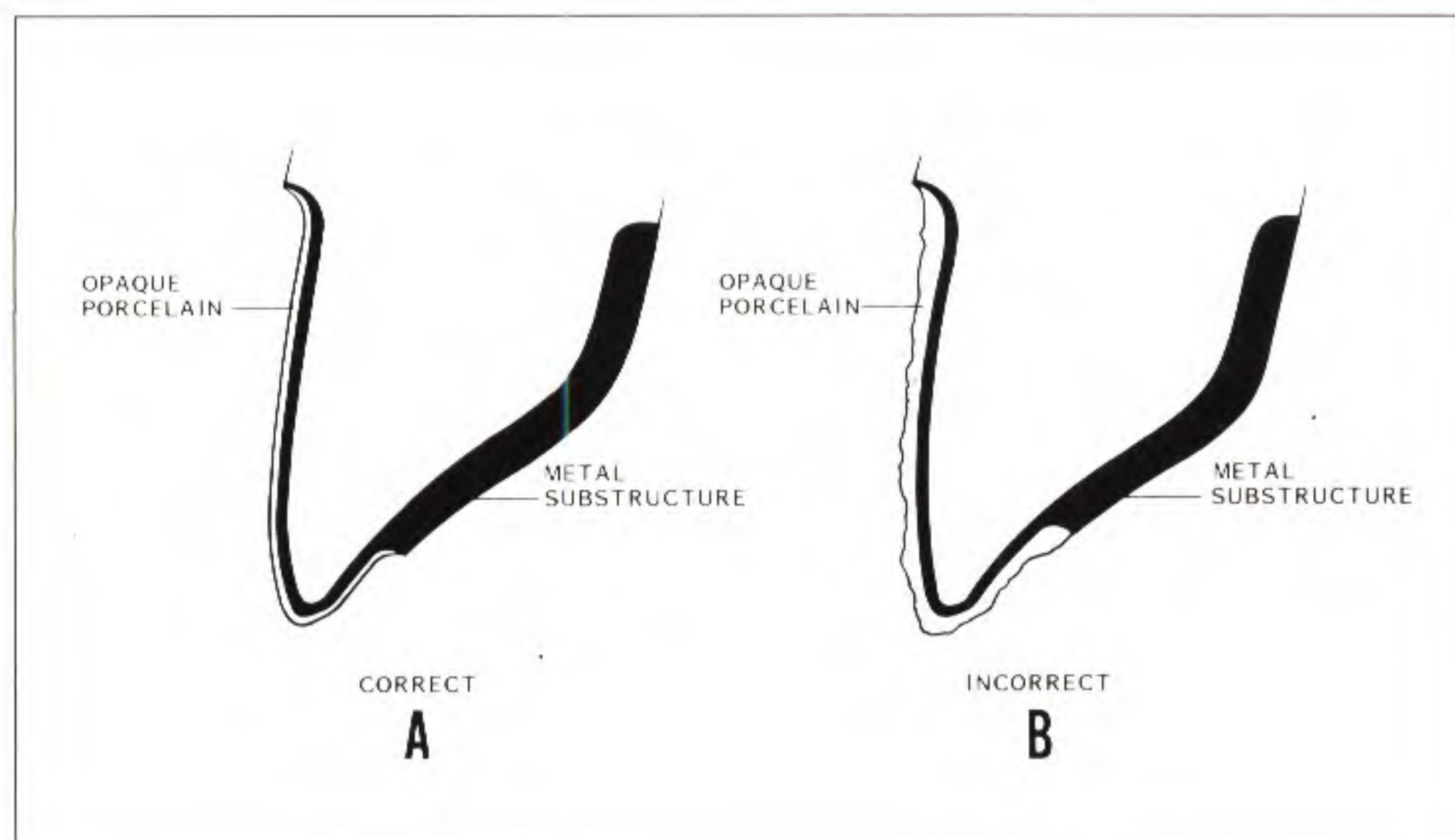


Fig 8-15 The fired opaque should be smooth and uniform in thickness (A) with care taken to avoid pooling at the porcelain-metal junction and the formation of a thick, irregular layer (B).

from one brand of porcelain to another and certainly from one metal ceramic alloy to the next. The range of thicknesses generally believed to be appropriate is 0.2 to 0.3 mm (Barghi and Lorenzana, 1982; Fowler and Tamura, 1987; Lacy, 1980; Naylor, 1986), although some authors recommend 0.1 to 0.15 mm (Dykema et al, 1986).

Obviously, since the formation of the porcelain-to-metal bond occurs with the opaque porcelain layer, proper application and firing are essential. The opaque porcelain is usually applied with either a glass rod or a porcelain brush.

No matter what instrument is used, the opaque porcelain can be applied and fired in one of two ways. First, you can attempt to completely mask the metal with a single opaque porcelain layer and use a second firing only to mask any remaining thin areas. Second, two separate firings can be planned so that the first application is a thin "wash" fired to the temperature recommended for the particular brand of porcelain. This initial layer wets the metal surface and is covered by a thicker second layer. There is a greater tendency for some opaque porcelains to crack on firing when applied too thickly. While these cracks are of little concern and can be easily corrected with another application of opaque porcelain, they certainly eliminate any advantage in completing the opaquing process in a single application and firing.

Despite the differences in both approaches, you should strive for a smooth, uniform thickness of opaque and avoid pooling of the opaque porcelain at the porcelain-metal junction and in grooves. A correctly placed and fired opaque layer should be

smooth and uniform in thickness (Fig 8-15, A) rather than be permitted to pool or buildup forming a thick and highly irregular layer after firing (Fig 8-15, B).

Anterior single crown with metal lingual surface (standard buildup technique)

Mixing opaque porcelain

Generally, porcelain manufacturers provide a special liquid medium, rather than distilled water, to mix their opaque powders (Fig 8-16). Dispense an adequate amount of the powders for the restoration(s) on a glass slab or some other ceramic surface (see Figs 8-9a and b). Do not add liquid directly on top of the porcelain, because this may result in air entrapment within the material. As pointed out previously, a metal spatula can contaminate the mix with metal particles when mixed vigorously on a ceramic slab (see Fig 8-5).

Specially designed glass rods have a rounded end for mixing and a pointed end for applying opaque porcelain (Figs 8-17a and b). If the porcelain soaks up the available liquid and still seems dry or cracks and wrinkles with attempts to mix the material, add more liquid. However, avoid adding too much liquid and creating too wet a mixture.



Fig 8-16 Opaque porcelain and opaque modifiers are available with their own special opaque liquid medium (Silhouette porcelain, Leach and Dillon).



Fig 8-17a The round end of the Tanaka glass mixing rod (Tanaka Dental).

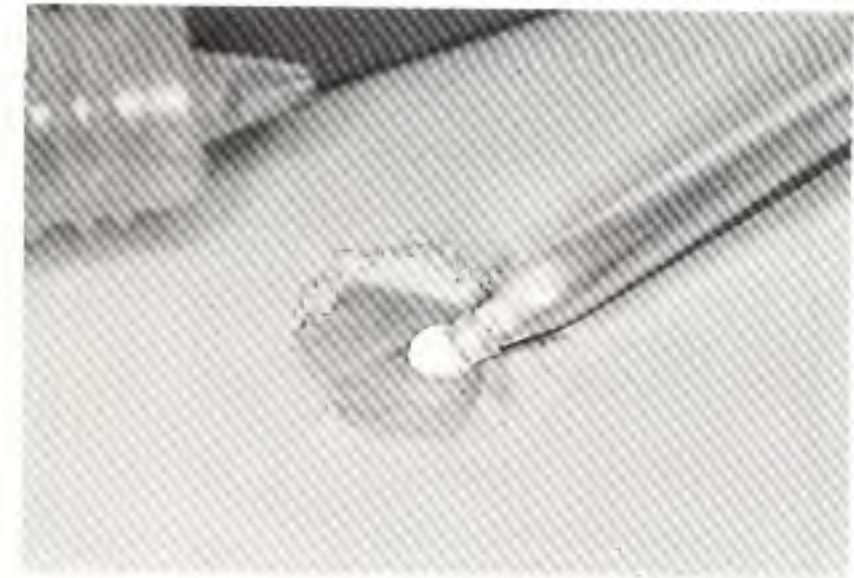


Fig 8-17b The opaque liquid and powder are carefully combined with a glass mixing rod so air is not incorporated in mixed opaque.



Fig 8-18 The areas to be opaqued on this oxidized restoration (Protocol alloy, Williams Dental Co) are lightly wetted with the opaque liquid. The casting can be vibrated to thoroughly wet these surfaces.



Fig 8-19 Using the pointed end of the Tanaka glass rod, opaque porcelain is placed on the most convex surface of the restoration.

Applying opaque porcelain—glass rod technique

First, lightly wet the oxidized metal substructure to be veneered with distilled water and gently vibrate the casting to thoroughly wet the surface (Fig 8-18). A wet surface makes porcelain application easier and reduces the possibility of trapping air between the porcelain and the metal. The thin film of water also will draw the opaque particles onto the metal surface.

Use the pointed end of the glass rod to apply the opaque porcelain. Begin by opaquing the most convex portion of the coping (Fig 8-19). Move the opaque toward the porcelain-metal junction from one interproximal area (Fig 8-20) to the other and cover the incisal edge. Then move the opaque over the incisal edge to cover the porcelain-bearing surface on the lingual aspect. Once the porcelain-bearing areas are completely covered, lightly tap the hemostat and the porcelain will settle into any concavities (Fig 8-21). If the application is started in or near these concavities,

there is a tendency for the material to pool immediately, and this will result in a thick opaque layer (see Fig 8-15, B). Since concavities are often adjacent to porcelain-metal junctions, any unnecessary thickness of opaque porcelain will result in a thin veneer of body porcelain or expose the opaque layer. Either situation will give the crown a very dull appearance, because the highly reflective opaque porcelain is at or near the surface. This is a significant esthetic and technical problem. Areas of exposed opaque porcelain are rougher than glazed body porcelain. If these areas of roughness are near the gingival one third, they will harbor bacteria and can act as an irritant to the soft tissue. On the other hand, if the opaque porcelain is exposed on an area of occlusal contact, it will present a highly abrasive surface that can wear opposing restorations or natural tooth structure. Unfortunately, exposed opaque porcelain cannot be glazed or polished.

Unlike body porcelains, opaque porcelain gener-



Fig 8-20 The tip of the glass rod is used to move the opaque porcelain toward the porcelain-metal junction until the entire porcelain-bearing surface is covered.

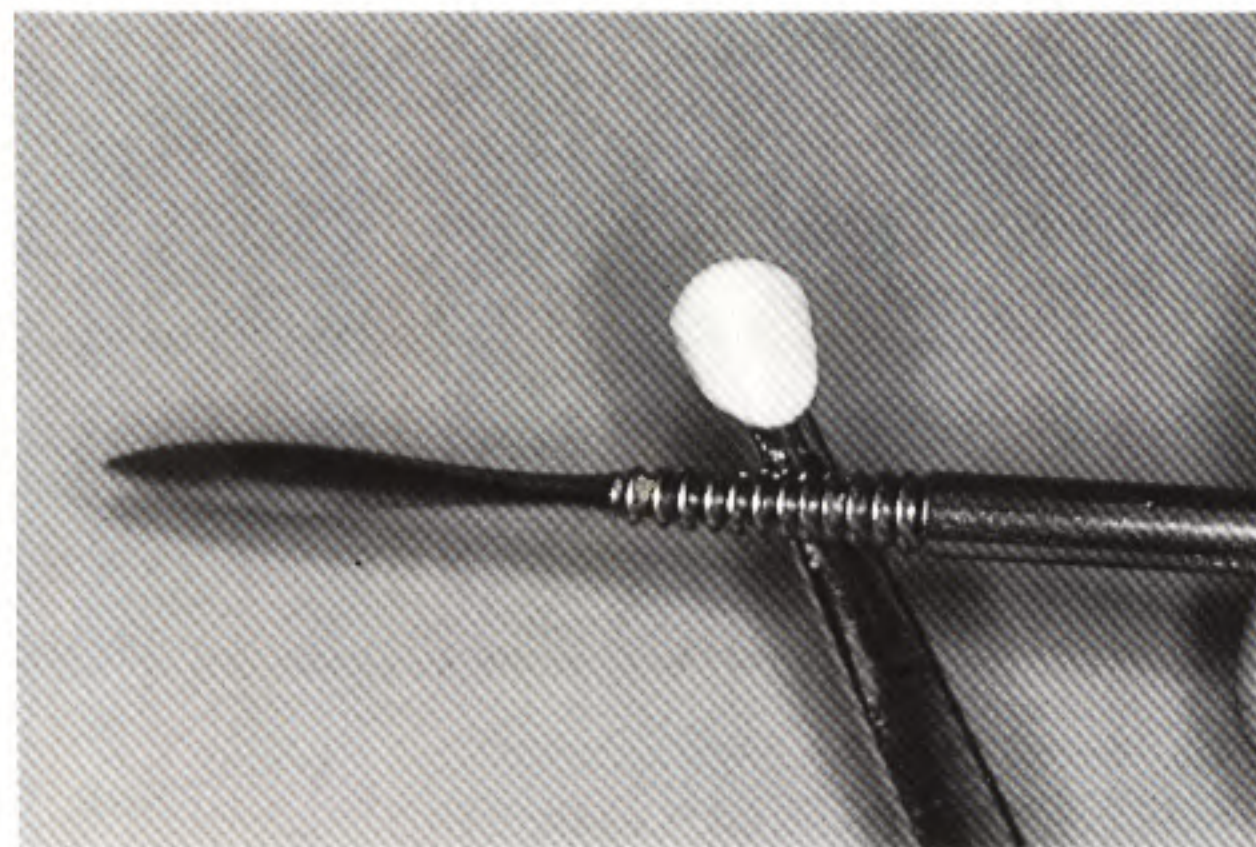


Fig 8-21 Lightly tap the hemostat with a metal instrument to condense the opaque porcelain and excess opaquing liquid will rise to the surface.

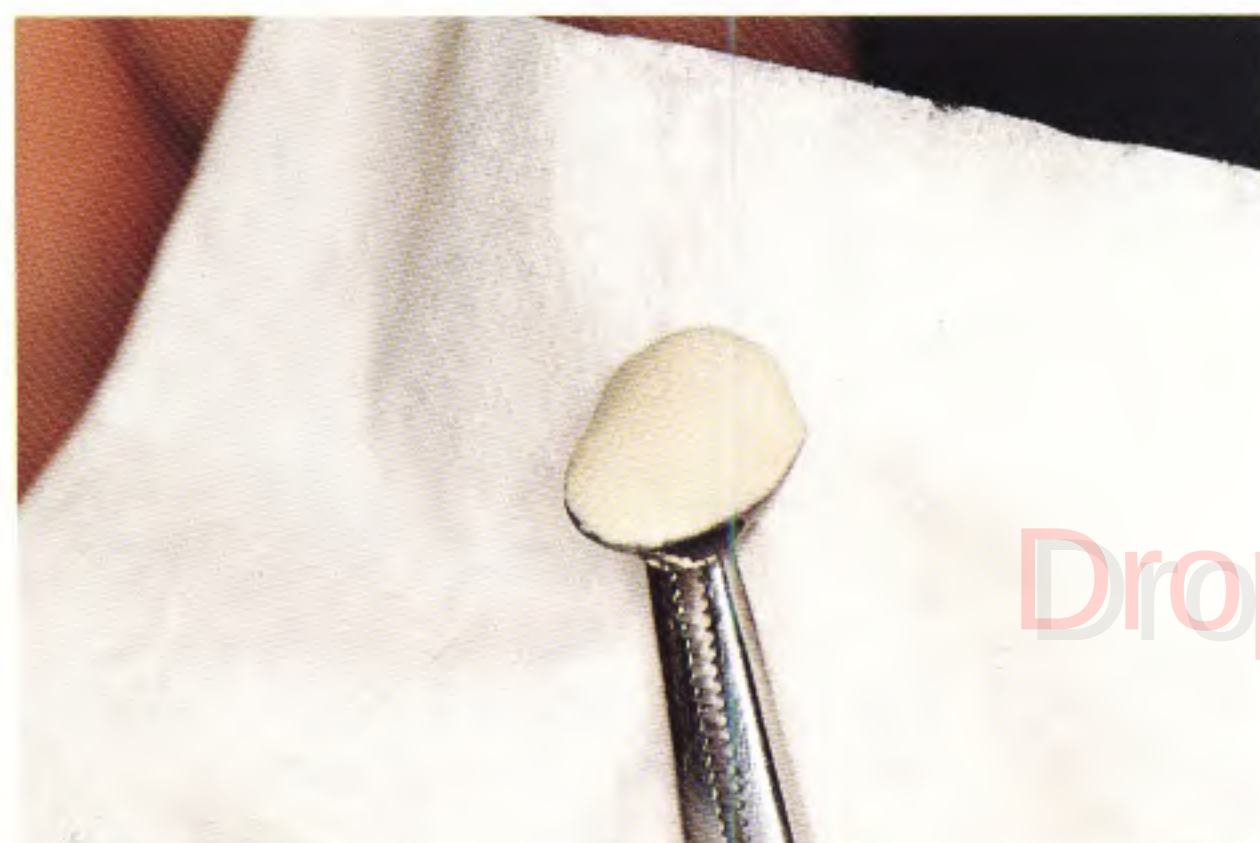


Fig 8-22 Place the edge of a tissue, or some other type of absorbent material, against an edge of the moist opaque porcelain. Hold the tissue in place until the liquid is absorbed and takes on a dull appearance.



Fig 8-23 Blend the opaque at the porcelain-metal junction to establish a gradual transition from opaque to external surface, as illustrated in Fig 8-15, A.



Fig 8-24 While holding the end of the hemostat, dry the opaque layer by exposing it to the heat radiating from the porcelain furnace muffle.



Fig 8-25 Remove any dried opaque from nonporcelain-bearing areas, such as facial metal margins, using a small, stiff-bristle brush.



Fig 8-26 Place the opaqued coping in the middle of the muffle stand and fire it according to the manufacturer's instructions.



Fig 8-27 A properly fired (sintered) opaque layer should have a sheen or eggshell glisten.



Fig 8-28 If a second opaque application and firing is needed, wet the first layer with opaque medium and then apply the second opaque layer.



Fig 8-29 The completed opaque layer should completely mask the oxidized metal substructure. Inspect and clean the inside of the casting and return it to its die and the master cast.

ally is not blotted. However, it is sometimes helpful to remove excess liquid, particularly if you are attempting to mask the metal substructure with the initial application. It is best to simply place a tissue or other absorbent, blotter-type material gently against an edge of moist opaque (Fig 8-22). Blotting the surface of a wet body porcelain buildup draws out the moisture by capillary action and the resulting surface tension packs (condenses) the particles more tightly together. But avoid blotting an entire surface, as you are apt to lift the opaque right off the metal substructure or otherwise disrupt the smooth surface you have created.

If, during the opaque application, areas of opaque appear rough and irregular, lightly tap the hemostat handle or move the serrations on a carver across the hemostat in a sawing motion. The vibrations created by either of these procedures will act to condense and smooth the wet porcelain into a more uniform layer. If the opaque mix is too wet, blot it with a tissue while it is on the glass slab. Excess moisture should be removed before the opaque is applied to the metal.

Make any additions to the opaque layer and gently blend the opaque at the porcelain-metal junction (Fig 8-23). Lightly tap the hemostat and dry the opaque by placing it in front of an open porcelain furnace muffle (Fig 8-24).

Carefully check to be certain that none of the opaque porcelain has extended past the porcelain-metal junction or onto the unveneered areas of the metal lingual surface. Remove these porcelain overextensions with a stiff brush. Be sure to inspect the inside of the coping.

Dry the restoration in front of the muffle once more and look for dried opaque porcelain on nonporcelain-bearing surfaces. Use the smaller stiff brush (see Fig 8-3) to remove this excess from the metal margin (Fig

8-25). It is always easier to remove dried porcelain from these areas before it is fired because once fired the porcelain must be ground off.

Put the restoration on a saggar tray and place the saggar tray in the middle of the muffle stand (Fig 8-26). Then fire the restoration according to the manufacturer's instructions adjusted to the firing parameters of your particular porcelain furnace (see Appendix B). A properly fired opaque layer will have a sheen or eggshell glisten (Fig 8-27).

If a second application of opaque porcelain is required, as will generally be the case, lightly wet the opaqued surface with opaque liquid (Fig 8-28). Apply the second opaque porcelain layer in the same manner as the first. Again, make every effort to keep this second layer as thin and uniform as possible.

The second application should completely mask the metal oxide color (Fig 8-29). Remember to carefully clean porcelain from areas not intended for veneering, both inside and out. Examine the fired restoration to confirm complete, uniform masking of the metal and clean, well-defined porcelain-metal junctions. If metal coverage is incomplete, do not hesitate to apply additional opaque porcelain where necessary.

Carefully return the opaqued coping to the master die to confirm complete seating (Fig 8-29). If the coping binds or fails to go on the die, do not force it to place. Remove the restoration and reexamine it internally under magnification. Incomplete seating on the die often is an indication that some particle of opaque porcelain or other debris are inside the crown. It is imperative that the problem be identified and eliminated before you proceed. Always resist the temptation to force the restoration on the die. If a crown is forced to place, invariably the die will be abraded slightly or chipped. The result will be a restoration that seats on the die but not on the prepared tooth.



Fig 8-30 Opaque porcelain can also be applied with a brush. Load the tip of a large brush and carry the porcelain to the metal substructure.



Fig 8-31a Some ceramists prefer to apply and fire a thin initial layer of opaque to thoroughly wet the porcelain-bearing surface.



Fig 8-31b The technique of masking the oxidized surface completely with the first layer of opaque is equally as popular.



Fig 8-32 Spray opaques in a variety of shades are commercially available (Shake N Spray, Leach and Dillon).



Fig 8-33a Premixed opaques are now available and various shades are provided in individual syringes (Bio-paque, Dentsply International).



Fig 8-33b The mixed opaque can be dispensed from the syringe as needed and applied with a brush.

DropBooks

Applying opaque porcelain—brush technique

If you do not have a glass rod, you can apply opaque porcelain with a brush. Simply mix the opaque porcelain as described previously (see Figs 8-17b and 8-18). Use the tip of your porcelain brush to lift a portion of the mixed opaque (Fig 8-30).

Apply the porcelain on the most convex part of the oxidized coping. Repeat the process several times until the porcelain-bearing area is completely covered with porcelain.

Alternatively, you may fire this thin layer (Fig 8-31a) or apply a thicker first layer (Fig 8-31b) and then fire the restoration. Apply a second layer of opaque as needed to mask the substructure. Dry and fire the restoration and you should have a uniform layer of opaque (see Fig 8-29).

Alternative methods of applying opaque porcelain

Conventional dental porcelains are offered in powdered form, but newer systems include spray opaques (Fig 8-32) and premixed opaques that can be applied with a brush (Figs 8-33a and b).

Dentin and enamel (body) porcelain application technique

The next step in the porcelain buildup procedure is to choose and properly mix those body porcelains that will be used in fabricating the porcelain veneer (see Fig 2-1 in chapter 2). All porcelain systems will list a specific dentin and an enamel porcelain that matches each specific shade tab in that system (Fig 8-34).

Tumble the individual porcelain jars to mix any fine particles that may have settled during storage (Fig 8-35). Also, be sure to wipe any instrument used in dispensing or mixing a porcelain before you place that instrument into a different bottle of powder. Dispense an adequate amount of dentin and enamel porcelain onto the mixing slab. Because dentin porcelain powders of different shades will look the same once mixed, color tags (organic dyes), previously discussed in chapter 2, can be added to intensify the color of a mix (Fig 8-36). Be careful not to unintentionally mix the different powders (dentin and enamel) with one another. Also, remember to discard the distilled water used to clean the brush during the opaquing phase. This water contains particles that have intense pigmentation and are very opaque. Even small amounts of opaque porcelain may alter

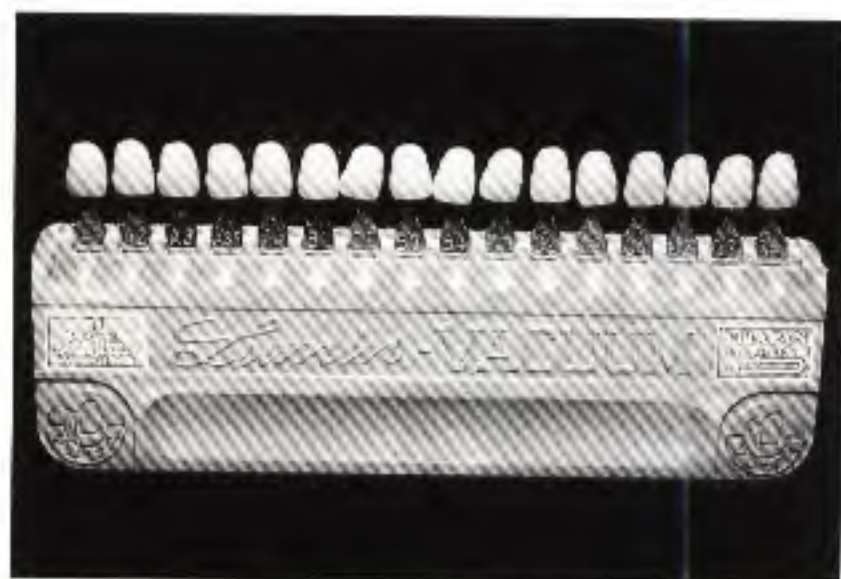


Fig 8-34 A shade guide for Vita's VMK 68 porcelain (Vident).



Fig 8-35 Tumble each porcelain jar before dispensing to thoroughly distribute any fine particles that may have settled during storage.



Fig 8-36 A red color tag (Optec Porcelain, Jeneric/Pentron, Inc) can be added to the body porcelain to intensify the color and improve the level of contrast between layers.



Fig 8-37 Mix the body powders (dentin and enamel) with the recommended liquid (Vita VMK 68 porcelain and modeling liquid are shown).

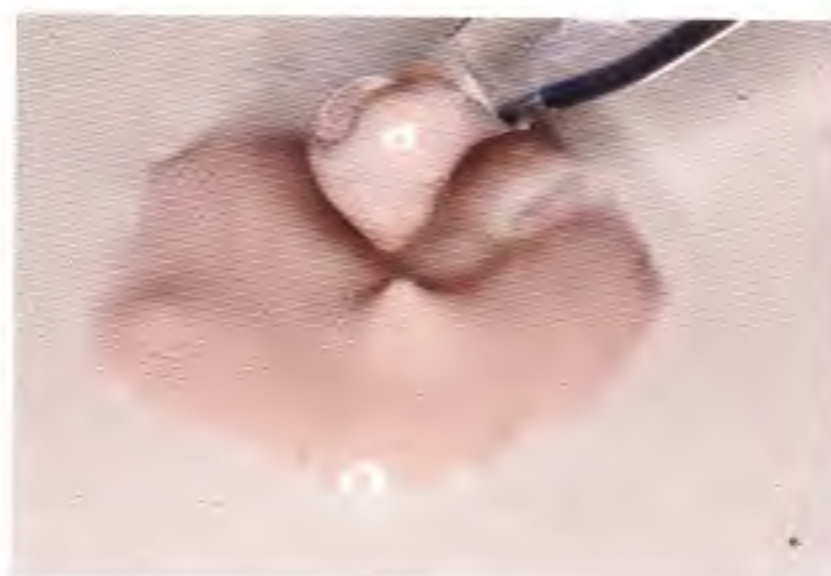


Fig 8-38 When properly mixed, dentin porcelain should have a smooth, cream consistency.



Fig 8-39 If too much liquid is added to the mix, use a tissue or blotting paper to remove excess liquid until the proper consistency is achieved.

the final shade and impair translucency, if they contaminate the body powders.

Mixing dentin porcelains

The technique for mixing body porcelains is virtually the same as that used to mix opaque porcelains in that a glass rod is preferred to a metal spatula and the liquid is carefully added to the powder to prevent the entrapment of air.

Combine the liquid medium recommended by the porcelain manufacturer with each of the porcelains (Fig 8-37). Some brands are mixed with distilled water, whereas other manufacturers supply a special body porcelain liquid for this purpose. The advantages of these special liquids are that they usually evaporate more slowly than water, and some are said to make the unfired porcelain mass more moldable and carvable.

A proper mix of body porcelain will have a thick creamy consistency (Fig 8-38). If the porcelain on the glass slab begins to dry out during the buildup procedure, it should be rewetted with distilled water rather

than the special liquid. As the special liquids evaporate, only the water is lost, while the additives they contain remain in the porcelain. Therefore, adding only distilled water generally is adequate. There are a few exceptions to this. Distilled water should not be mixed with some liquids, so always read the manufacturer's directions for specific recommendations.

Proper moisture content is the key to building porcelain. When all the porcelain particles are incorporated and a homogeneous mix is achieved, any excess moisture should simply be blotted away with a tissue (Fig 8-39). A mix that is too wet makes it difficult to build up the restoration or maintain the restoration's shape. Conversely, if the porcelain mix is too dry, it will not uniformly adapt to a previously applied layer, and air pockets can be entrapped more easily.

During the mixing procedure, avoid anything that might cause air entrapment. For example, do not fold the material onto itself, and avoid excessive stirring. To remove air bubbles, the mixing instrument can be vibrated by pulling a serrated instrument across the handle. On occasion, air bubbles can be seen rising to the surface of the mix while vibrating.



Fig 8-40 Wet the bristles in a distilled water bath and drag the bristles through a V-shaped notch cut in an adjacent sponge while slowly rotating the brush.



Fig 8-41 Continue rotating the brush as it is dragged out of the distilled water and across the sponge.



Fig 8-42 The resultant brush should have a distinct sharp "point." Alternatively, many technicians prefer to wet their brush by placing it in their mouth and simply twisting it. Although the technique may be different and less hygienic, the result is virtually the same and the loose-bristled brush is "pointed."

Another practice that should be avoided is rewetting porcelain that has completely dried out on the glass slab. When mixed porcelain dries out, air-filled voids are left as moisture evaporates. It is impossible and impractical to try to eliminate these air pockets when liquid is reapplied to moisten the powders. In fact, the voids are often so large and so numerous that you may even be able to see the air bubbles in the mix. Vigorous condensation procedures cannot eliminate such large porosities. The porcelain, both on the mixing slab and in the buildup, should be constantly remoistened with distilled water. Never allow porcelain to dry out completely during the buildup procedure.

Applying dentin porcelain

The goal of the dentin porcelain buildup procedure is to apply and condense enough porcelain to create a restoration that is 10% to 15% larger than normal. This overbuilding will accommodate the enamel veneer that will be placed over the dentin layer and help to compensate for shrinkage of the porcelain. Although some ceramists prefer to use spatulas, most will use a high-quality sable brush to create the porcelain buildup. The success of this buildup technique relies on a brush that is "pointed," or transformed from a large blunt tip to a fine tapered point.

"Pointing" the porcelain brush (Figs 8-40 to 8-42)

The first step in the buildup procedure requires the refinement of some method to rapidly "point" ceramic

brushes to facilitate the pickup and placement of porcelain addition.

The dentin buildup technique (Figs 8-43 to 8-50)

Some ceramists prefer to begin the buildup procedure by first applying dentin porcelain along the porcelain-metal junction lines and thoroughly condensing the porcelain by alternating vibration and blotting. Such a practice is thought to reduce the tendency of porcelain to pull away from these areas during firing. On the other hand, the more common technique with a basic buildup approach is to simply build up the restoration to full contour and rely on sound condensation techniques to control shrinkage at the porcelain-metal junction. This latter technique will be illustrated for the standard buildup of a single-unit crown. For the sake of completeness, the method of first condensing at the porcelain-metal junction will be demonstrated later with the application of opacous dentin.

Because the lingual surface of this restoration has been restored in metal, the porcelain is condensed principally by blotting from the lingual aspect, as illustrated in Fig 8-48. If the lingual surface were to be restored in porcelain, then blotting would have been done on both the facial and the lingual surfaces. Remember, blotting relies on capillary action to draw the liquid toward the absorbent medium, and in the process porcelain is condensed in that same direction. Therefore, it is advisable to blot (condense) from as many directions as possible.

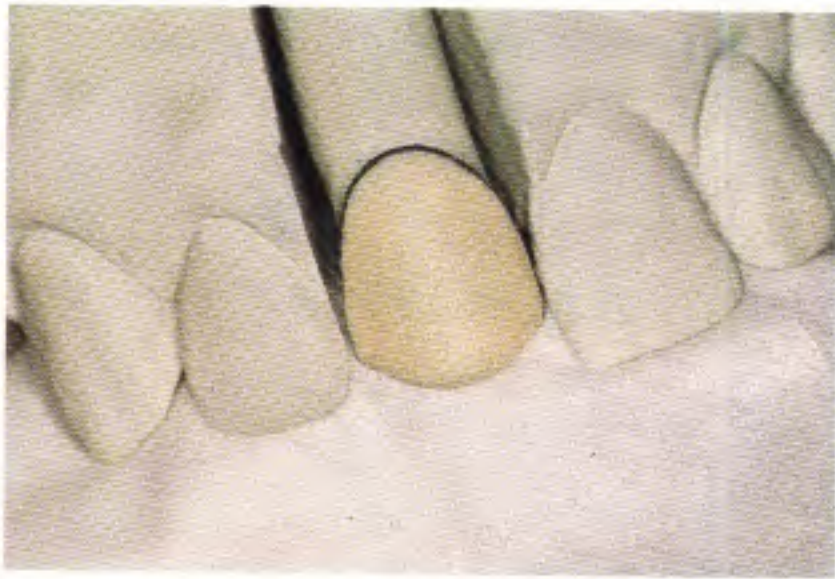


Fig 8-43 Carefully return the cleaned, opaqued coping to the master cast. Place folded tissue or blotting paper on the lingual side of the restoration.



Fig 8-44 To minimize the potential for entrapping air in the porcelain, move the tip of the "pointed" brush through the mixed dentin porcelain. Remove the brush with the dentin porcelain captured on the brush tip.



Fig 8-45 Apply the porcelain to the most convex surface (midfacial area) on the restoration.

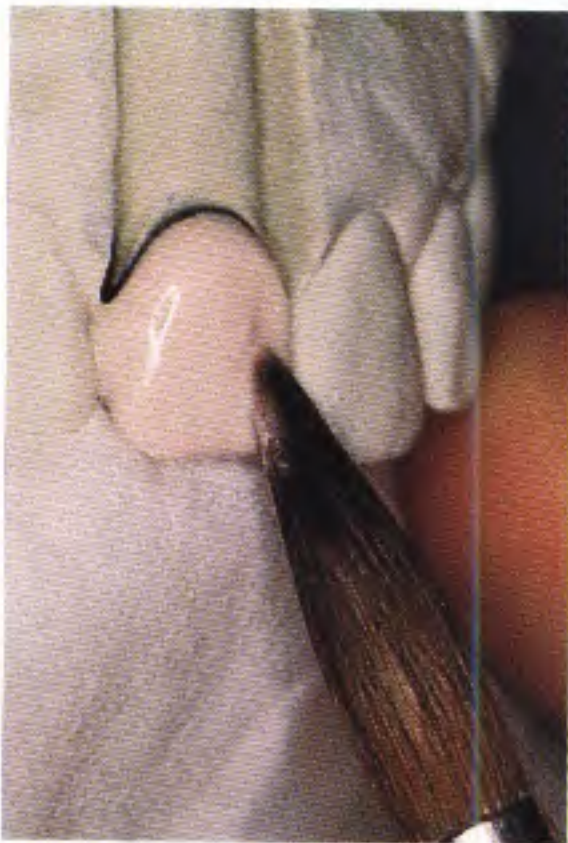


Fig 8-46 Gently coax the porcelain toward the interproximal and incisal areas. Add more porcelain to the facial surface and use a light tapping motion to move the porcelain along the porcelain-metal junction.



Fig 8-47 Move the porcelain down to the incisal edge and lightly blot the buildup to condense the porcelain on the substructure. Place additional dentin porcelain in the incisal region and move it from one interproximal area to the other (movement here is from the mesial interproximal to the distal interproximal area).



Fig 8-48 To create the mesial-facial line angle, wipe the brush to dry it slightly and reduce the "pointing," then lightly move from the mesial-lingual area to the mesial-incisal area. Control the flow of the material and condense the buildup by periodically blotting the wet porcelain with the tissue. Dry the brush a little more to further flatten the tip and, returning to the mesial aspect, use light gingival-to-incisal strokes on the entire facial surface to create the desired facial contour.



Fig 8-49 (left) Point the brush and add additional dentin porcelain to the lingual aspect of the incisal edge. Smooth and condense the incisal edge from the lingual and facial aspects.

Fig 8-50 (right) Add additional porcelain to complete the mesial and distal corners. The restoration should now possess the approximate shape of a central incisor. At this point, the dentin buildup should be slightly oversized but retain the outline form of a central incisor.



Cutting back the dentin buildup

With the buildup complete, you are now ready to remove dentin porcelain from those areas of the crown where you would like to have enamel porcelain. The procedure of removing dentin porcelain for enamel placement is referred to as the "dentin cutback."

If too much dentin is applied the restoration can be overbuilt (Fig 8-51, A). The fired crown will be overcontoured even if the "cutback" is performed correctly (Fig 8-51, B). So it is important that the restoration be shaped to proper contour initially (Fig 8-52, A). Make certain to leave an appropriate amount of dentin

porcelain in the incisal and middle one thirds of the crown (Fig 8-52, B).

Dentin cutback technique (Figs 8-53 to 8-59)

The following technique for cutting back the dentin porcelain should be considered a general approach to the procedure. How much dentin porcelain is removed and from what areas are actually determined by the esthetic demands of each particular case. In other words, there is no single standard cutback that can be used for all patients. To the contrary, the amount of enamel and translucent porcelain that

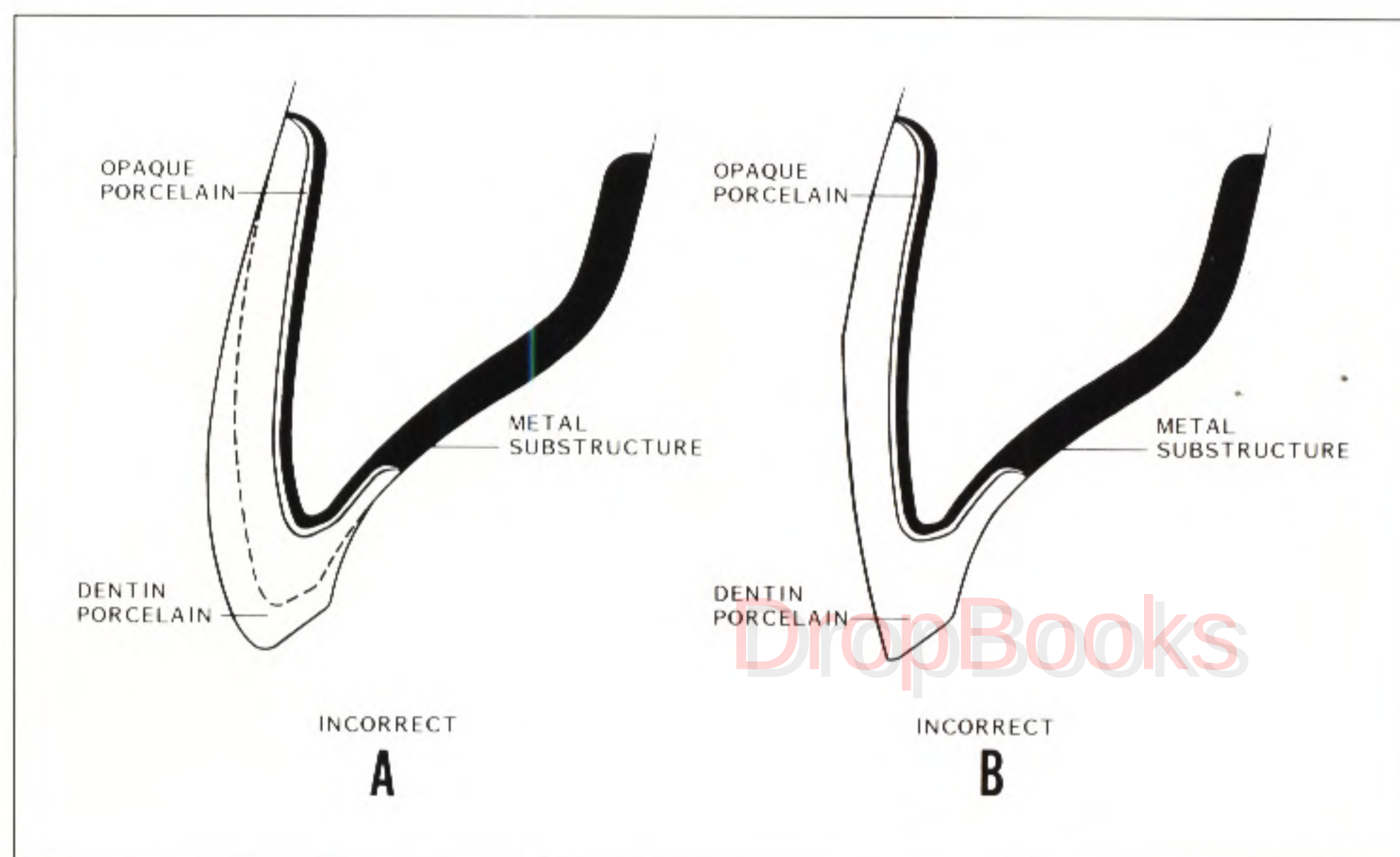


Fig 8-51 If dentin porcelain is overbuilt (A), the amount of dentin remaining after the cutback may also be incorrect (B).

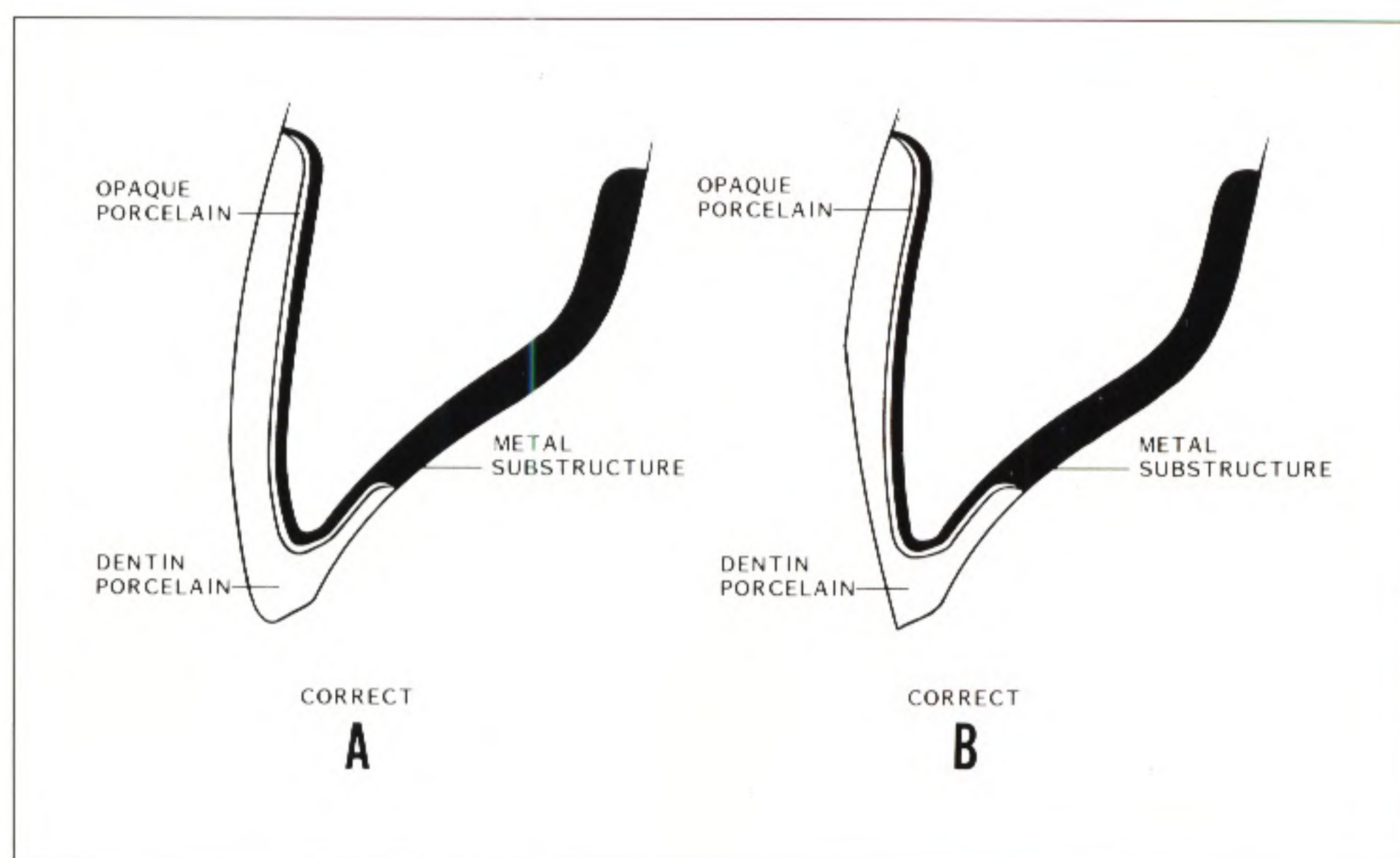


Fig 8-52 When the restoration has the correct anatomical contours and is slightly overbuilt (A) by 10% to 15%, the dentin cutback will also be correct (B).

should be used to reproduce an individual crown will vary markedly with the age of the patient. Therefore, look to the laboratory authorization (work order) or doctor's sketch, if there is one, to determine the extent and depth of the dentin cutback.

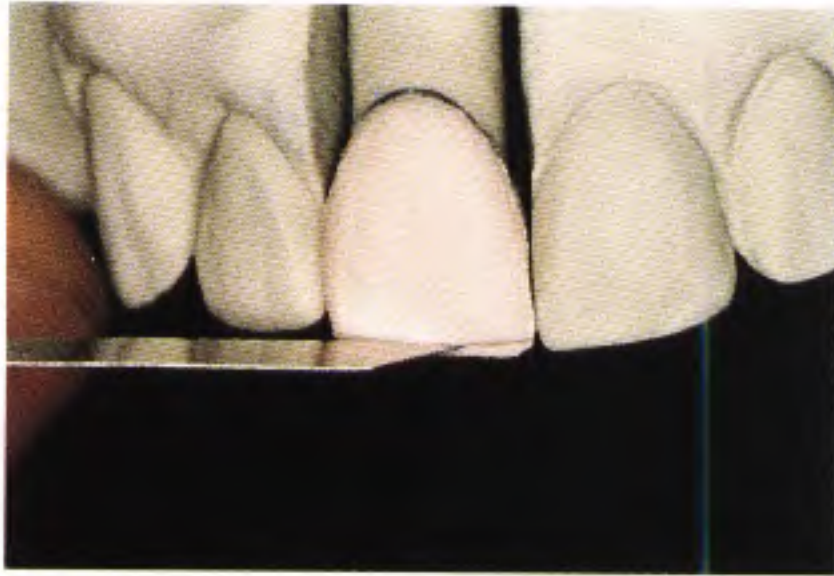


Fig 8-53 Generally, all you need for the porcelain cutback procedure is a razor knife and your porcelain build-up brush. Use a razor knife to cut back the incisal edge from between 1.0 to 1.5 mm.



Fig 8-54 Remove dentin porcelain at the mesial interproximal line angle. Extend the cut to the junction of the middle and gingival one thirds for younger patients.

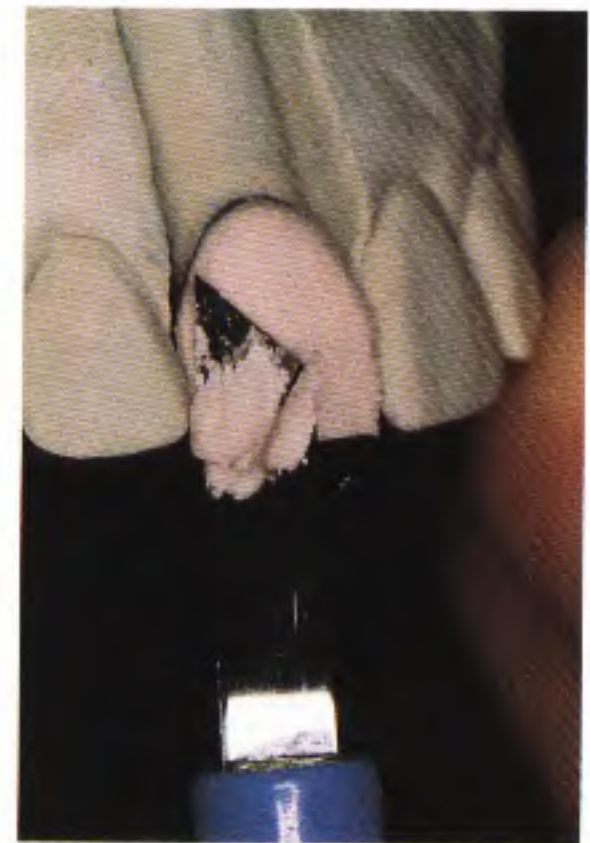


Fig 8-55 Cut across the middle one third. Stop the cutback at the distal interproximal area.



Fig 8-56 At the distal interproximal line angle, make a cut from the incisal edge toward the gingival one third as far as required for the esthetics of the case. Then cut back the middle one third of the facial surface as necessary.



Fig 8-57 Examine the restoration from an incisal view for symmetry and adequacy of the cutback.



Fig 8-58 Smooth the cutback areas with the porcelain brush so the transitions from dentin to enamel porcelain are gradual rather than abrupt. Assess the depth and incisal-gingival length of the cutback.

Fig 8-59 With restorations for younger patients, you may need to develop mamelons. With a pointed brush, create two depressions on the facial surface with vertical strokes from incisal to gingival. You can accentuate the incisal notches or fill them in for a more subtle appearance. Alternatively, you could use a knife to make these same facial cuts. At this point the restoration is now ready for the application of enamel porcelain.



Mixing the enamel porcelain (Figs 8-60 and 8-61)

The same recommendations for mixing opaque and dentin porcelain apply for the mixing of enamel porcelain.



Fig 8-60 Using a glass rod or other mixing instrument, add the manufacturer's buildup liquid (or distilled water) to the powder and stir gently. Generally, the enamel mix is slightly wetter than the dentin mix to facilitate its addition to a previously applied and condensed dentin layer.



Fig 8-61 Ideally, the mixed enamel porcelain should have a consistency that permits it to be readily picked up by a properly pointed porcelain brush.

Applying enamel porcelain (Figs 8-62 to 8-72)

When applying the enamel porcelain layer, be careful in the placement of each increment to avoid trapping air between additions. Also, avoid "working" the new layer of porcelain into the initial dentin buildup. In other words, maintain a well-defined border at the junction of the layers.

The esthetics of each case will vary such that in some instances the enamel porcelain is backed by dentin porcelain; or, you may have to extend enamel porcelain over the incisal edge and slightly onto the lingual surface. With a clean brush, remove any porcelain beyond the porcelain-metal junction with the brush tip. The restoration should be neat, clean, and slightly overbuilt to accommodate the firing shrinkage of the porcelain.

You can condense the porcelain buildup by lightly tapping the cast itself (vibration method) followed by blotting with absorbent material (capillary action). Or you may prefer to use a small mallet for tapping the cast (see Fig 8-8). You may also condense the buildup with a whipping brush (a form of vibration) followed by blotting. It is important to note that excessive whipping should be avoided, because there is a tendency to pull particles of enamel porcelain down over the dentin layer and vice versa. This action can cause a dilution of the dentin color, a loss of translucency, or lowering of the value (graying) of the overall restoration as enamel particles are incorporated into the dentin layer. Whether for purposes of condensation or not, the whipping brush helps to smooth the porcelain surface and blend the enamel porcelain into the dentin layer (see Fig 8-67).

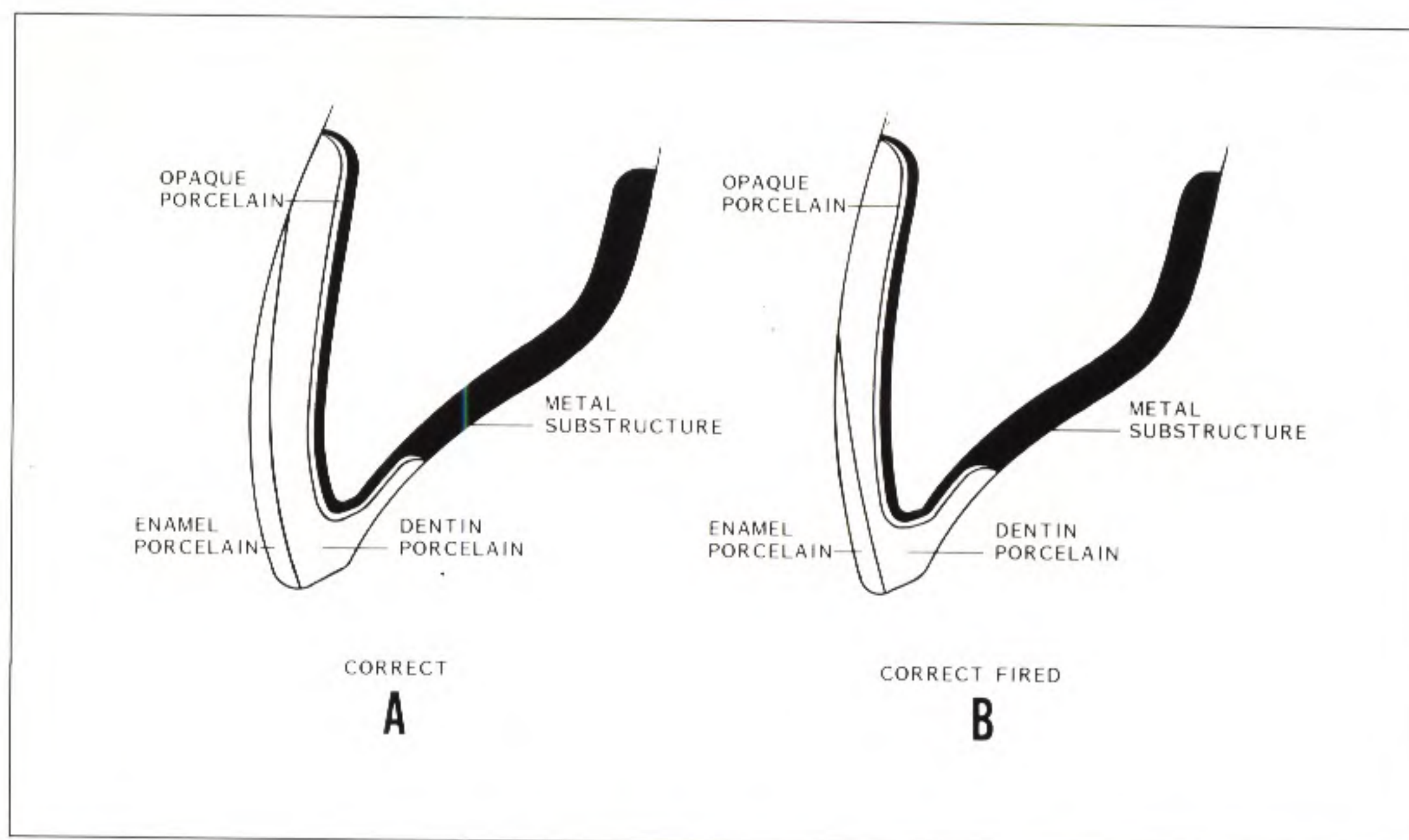


Fig 8-62 The goal here is to create a crown with an enamel porcelain veneer placed over a correct thickness of dentin porcelain (A) so the fired restoration has the proper final contour and enamel coverage (B). Although not illustrated, translucent porcelain can be applied over this buildup.



Fig 8-63 With a pointed brush, apply enamel porcelain to one corner of the cutback (mesial aspect shown).

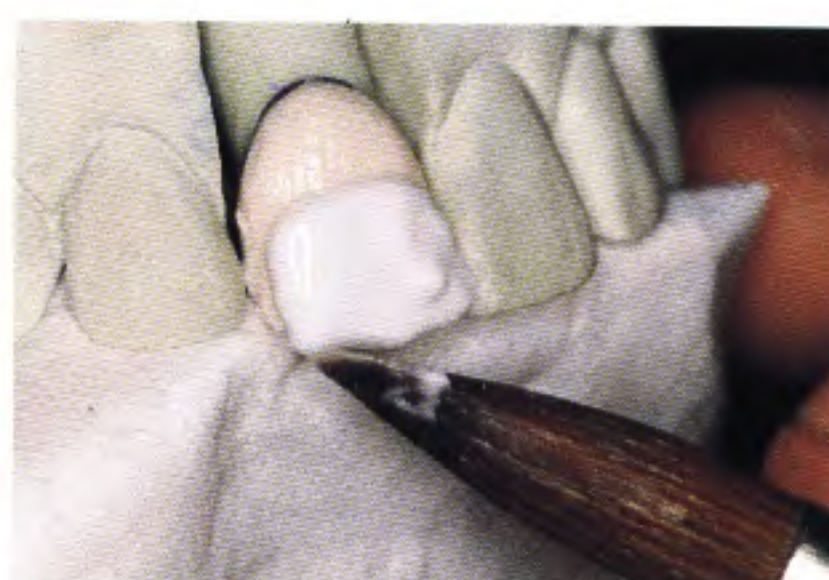


Fig 8-64 Add more enamel porcelain and move it across the facial surface in the incisal one third. Push the wet mix toward the middle one third of the crown and work it into the opposite (distal) interproximal line angle.



Fig 8-65 Blend the enamel porcelain at the junction of the middle and gingival one thirds and begin to establish the incisal edge and condense the porcelain by blotting periodically.



Fig 8-66 With additional enamel porcelain, complete the incisal edge length and the mesial-incisal line angle. Work your way along the incisal edge to create more of a distal-incisal line angle.



Fig 8-67 Blend the enamel porcelain into the gingival one third on the facial surface. Re-create the interproximal contours and line angles.



Fig 8-68 Shape the mesial-incisal corner as required for each case. Examine the buildup from an incisal view and evaluate the overall shape. Make certain the restoration is slightly overbuilt.



Fig 8-69 Condense the buildup.



Fig 8-70 Next, use your thin razor knife to cut and shape the mesial and distal interproximal areas. This procedure also removes any unwanted porcelain below the interproximal contact areas.



Fig 8-71 Carefully remove the crown from the master cast. Add enamel porcelain to the small dimples in each interproximal contact area. Overbuild these areas by approximately 0.5 mm to compensate for the porcelain shrinkage using either enamel or translucent porcelain.



Fig 8-72 Remove excess porcelain from the porcelain-metal junction and clean the facial metal collar of any porcelain with a small brush or your pointed porcelain buildup brush. Smooth the entire buildup with the whipping brush. Finally, inspect and clean the inside of the casting before firing the porcelain.



Fig 8-73 Place the restoration on a saggar tray and carefully position the buildup in the center of the porcelain furnace's muffle stand.



Fig 8-74 This wet porcelain buildup was either not dried long enough or was suddenly exposed to high heat so that the moisture in the porcelain produced steam, which caused portions of the buildup to "pop off" the metal substructure.



Fig 8-75 A properly fired porcelain body bake should have a pebbly or "orange peel" appearance. Examine the restoration for deficiencies in the restoration's outline form and contour, such as an inadequate mesio-incisal corner. These discrepancies will be corrected with a second body bake.

The firing procedure

The large bulk of the buildup will require more time to dry and pre-heat than the opaque porcelain. Adhere to the manufacturer's recommended drying times (see Appendix B).

Put the restoration on a saggar tray and place it on the muffle stand of the porcelain furnace (Fig 8-73). Failure to thoroughly dry the buildup may cause some of the internal moisture to vaporize and actually "pop" the unfired porcelain off of the metal substructure (Fig 8-74).

Properly matured porcelain will vary in appearance according to the different manufacturers' recommendations. However, most porcelains have a slightly rough, pebbly or "orange peel" appearance when fired correctly (Fig 8-75). Do not underfire the porcelain. Porcelain that has not matured properly has no shine to the surface and internally it has a cloudy appearance. Unfortunately, additional firing may not correct this problem, and the resulting porcelain will be weak and brittle. Restorations with underfired porcelain often have to be stripped from the metal and rebuilt. On the other hand, overfired porcelain appears to be glazed and the surface has little or none of the pebbly appearance mentioned previously. Other problems that may be present with overfired porcelain are excessive translucency and slumping or rounding and the loss of anatomic contours.

In the hands of an experienced ceramist, many single-unit crowns and even some fixed partial den-

tures can be fabricated with one to two buildups and firings. Yet you should not hesitate to make needed additions. Modern porcelains appear to be stable after multiple firings. Correction bakes may be a matter of routine until you gain more experience and improve your skills. As a rule, the same porcelain (dentin, enamel, or translucent) that was initially placed in an area is used for additions to that same area. However, the firing temperature is usually lowered 10°C with each correction bake so that the initial porcelain buildup is not affected. In addition, there is less bulk of porcelain with each subsequent correction, which allows for complete maturation at a slightly lower temperature. Again, follow the recommended firing schedule for each brand of dental porcelain.

Inspect the inside of the crown for evidence of debris and then reseat the restoration on the master cast and evaluate it for color and contours.

After these procedures are completed, clean the restoration in distilled water in an ultrasonic unit or steam clean. At first glance it is evident that this restoration will need a second bake to build up the mesioincisal corner (see Fig 8-75). Rather than subject the crown to multiple firings, it is best to proceed to the adjusting and finishing procedures in the event some other areas need correction. In this way, the second firing can correct not just one but all the deficiencies identified following the first bake. This restoration is now ready for occlusal adjustments and contouring (see chapter 9).

Alternative buildup techniques

Anterior single crown with lingual porcelain (lateral segmental buildup technique)

(Figs 8-76 to 8-86)

The standard dentin and enamel porcelain technique previously illustrated can also be used for anterior crowns with the lingual surface restored in porcelain (Fig 8-76). For younger patients or individuals with increased incisal translucency, restorations can be fabricated with an alternative method, referred to as the lateral segmental buildup technique.

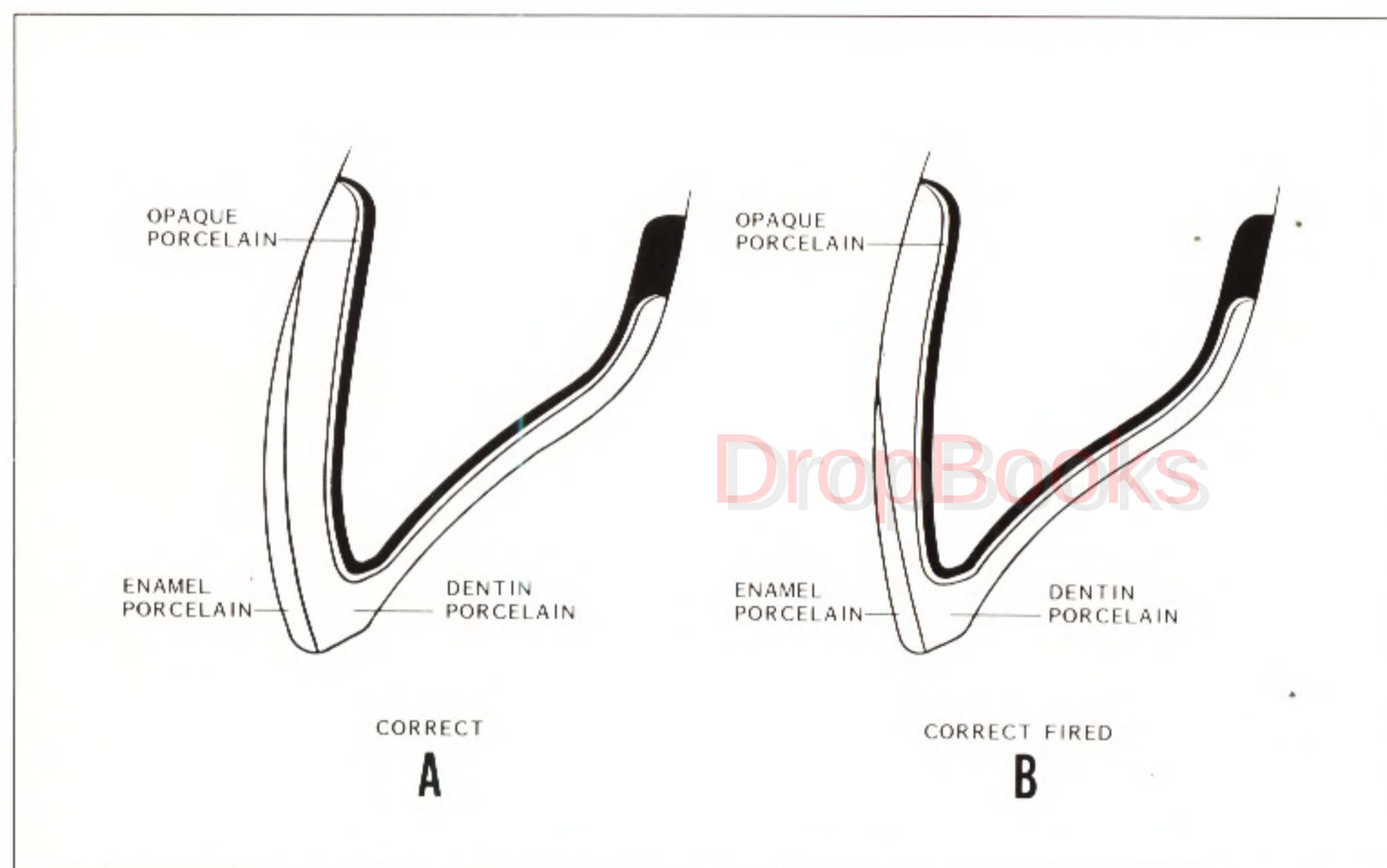


Fig 8-76 The layers of dentin and enamel porcelain for restorations with porcelain lingual surfaces should also be slightly overbuilt (A), to compensate for firing shrinkage so the final restoration has proper contours and esthetics (B).



Fig 8-77 Apply and fire opaque to mask the underlying metal.

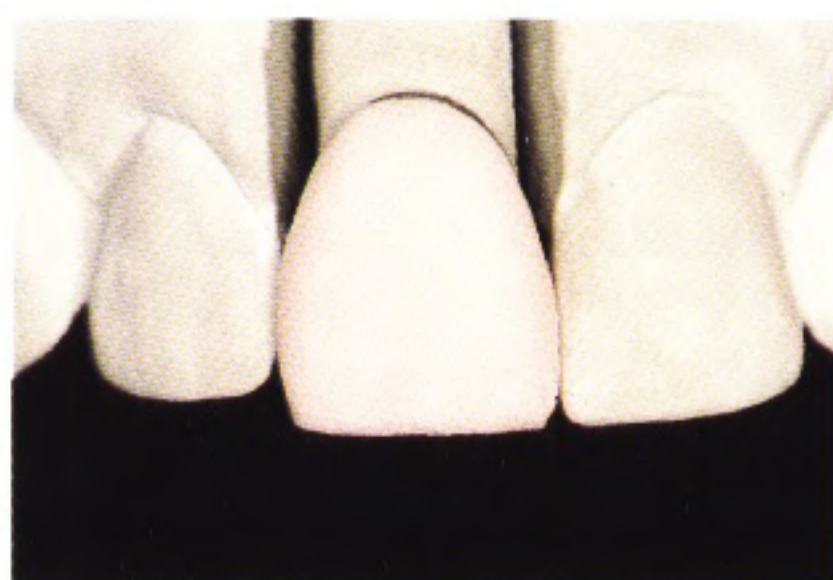


Fig 8-78 Complete and smooth the dentin buildup as described previously.



Fig 8-79 Create three developmental lobes with the pointed brush.



Fig 8-80 Invert the cast and place translucent porcelain in the two developmental grooves. Apply enamel porcelain to one interproximal area (mesial shown).



Fig 8-81 Next, apply a 50:50 mixture of enamel and translucent porcelain (color-coded pink for the purposes of illustration).



Fig 8-82 Place a second layer of enamel porcelain to the right of the 50:50 mixture of enamel and translucent porcelain and to the left of the translucent porcelain in the developmental groove.



Fig 8-83 Continue this process until the entire crown is built to full contour. Smooth the facial surface and then condense and blot the buildup.



Fig 8-84 Finally, use the whipping brush to gently smooth the entire porcelain buildup.

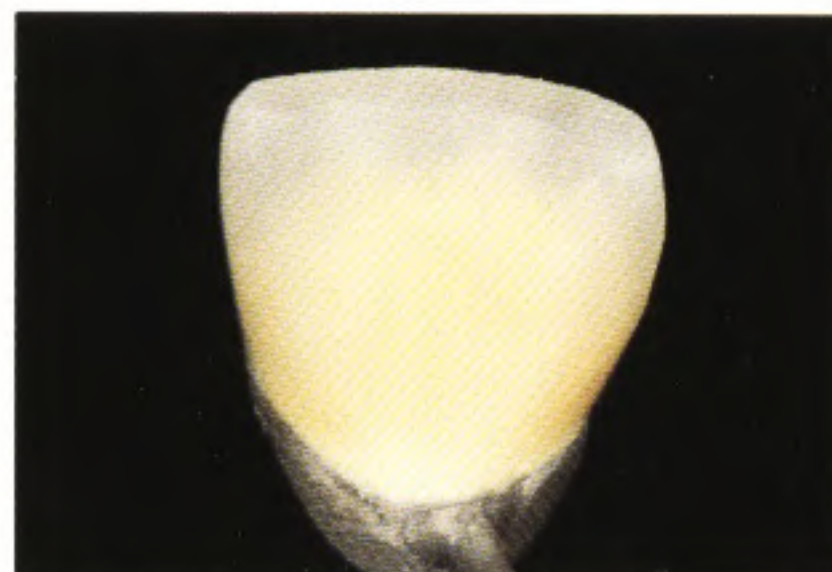


Fig 8-85 Once the porcelain has been fired, you should be able to observe demonstrable mamelons in the restoration (lingual view).



Fig 8-86 Note that the porcelain was well condensed and did not pull away from the porcelain-metal junction, and the blend of enamel and dentin porcelain is distinct yet gradual. It is also apparent that the restoration will require a second bake to restore more cervical contour. Because other areas of the restoration might need correction, the second bake will be performed in chapter 9, after preliminary adjusting and finishing of the restoration.

Posterior single crown with metal occlusal surface (Figs 8-87 to 8-93)

The technique for applying porcelain to a posterior crown with a metal occlusal surface is virtually the same as that used for anterior teeth. One major difference may be the need to incorporate a greater level of characterization to posterior teeth. Therefore, this example will serve to illustrate how to incorporate opacous dentin porcelain (a body modifier) into the buildup.



Fig 8-87 The crown substructure is adjusted, finished, and oxidized (Protocol alloy, Williams Dental Co).

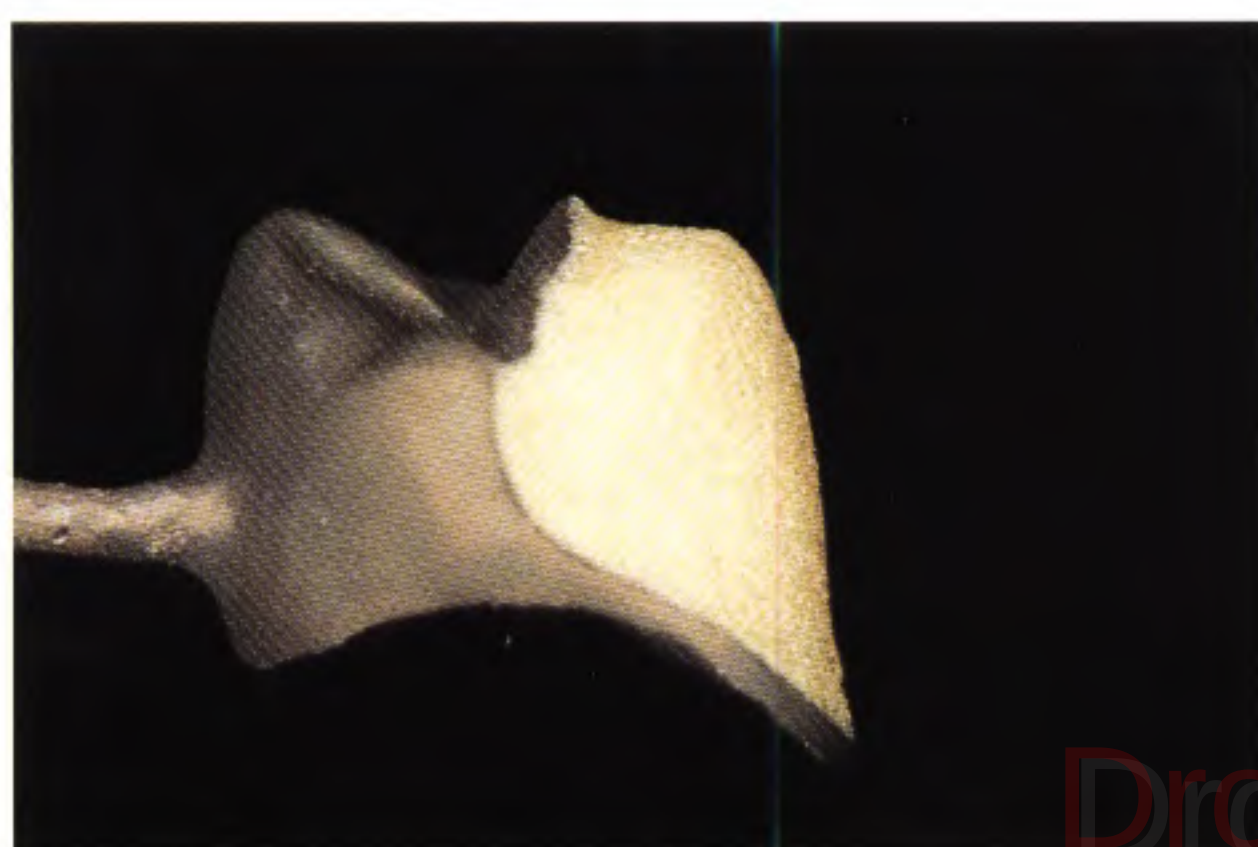


Fig 8-88 Lateral view of the coping after firing of the second layer of opaque porcelain. The opaque has a matte finish with no evidence of gray areas, which would indicate metal show-through.



Fig 8-89 Several porcelain manufacturers offer kits of opacous dentin porcelains to add internal color to the porcelain buildup (eg, Vita VMK 68 Opacous Dentin Porcelains, Vident). Opacous dentins are dentin porcelains with a higher chroma than conventional dentin porcelains (Korson, 1990). They are particularly useful for placement in areas where more intense color is desirable or where minimal porcelain thickness is possible.

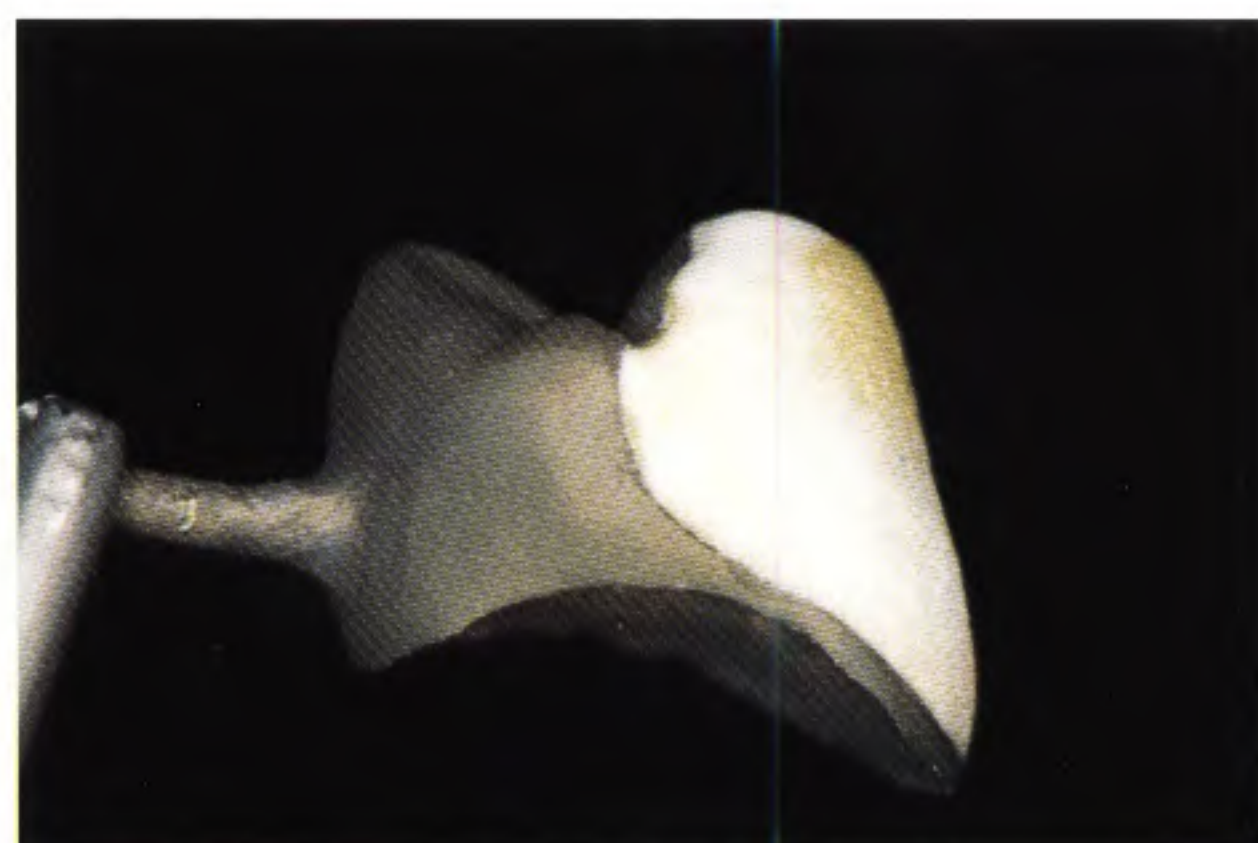


Fig 8-90 Lateral view of opacous dentin (Vita 577, Vident) applied and condensed. Customarily, the opacous dentin is placed and fired together with the first body bake rather than separately, as shown here.

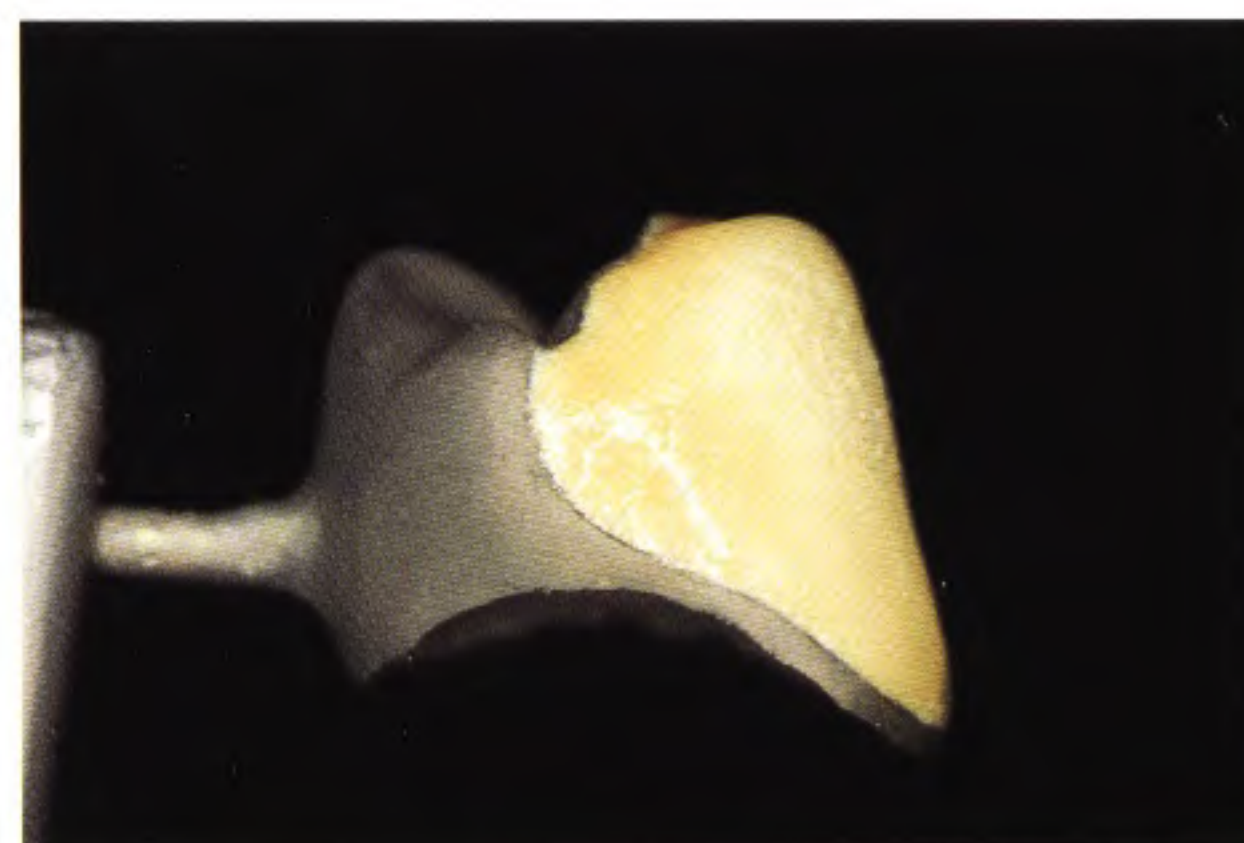


Fig 8-91 Lateral view of opacous dentin (Vita 577, Vident) after firing.

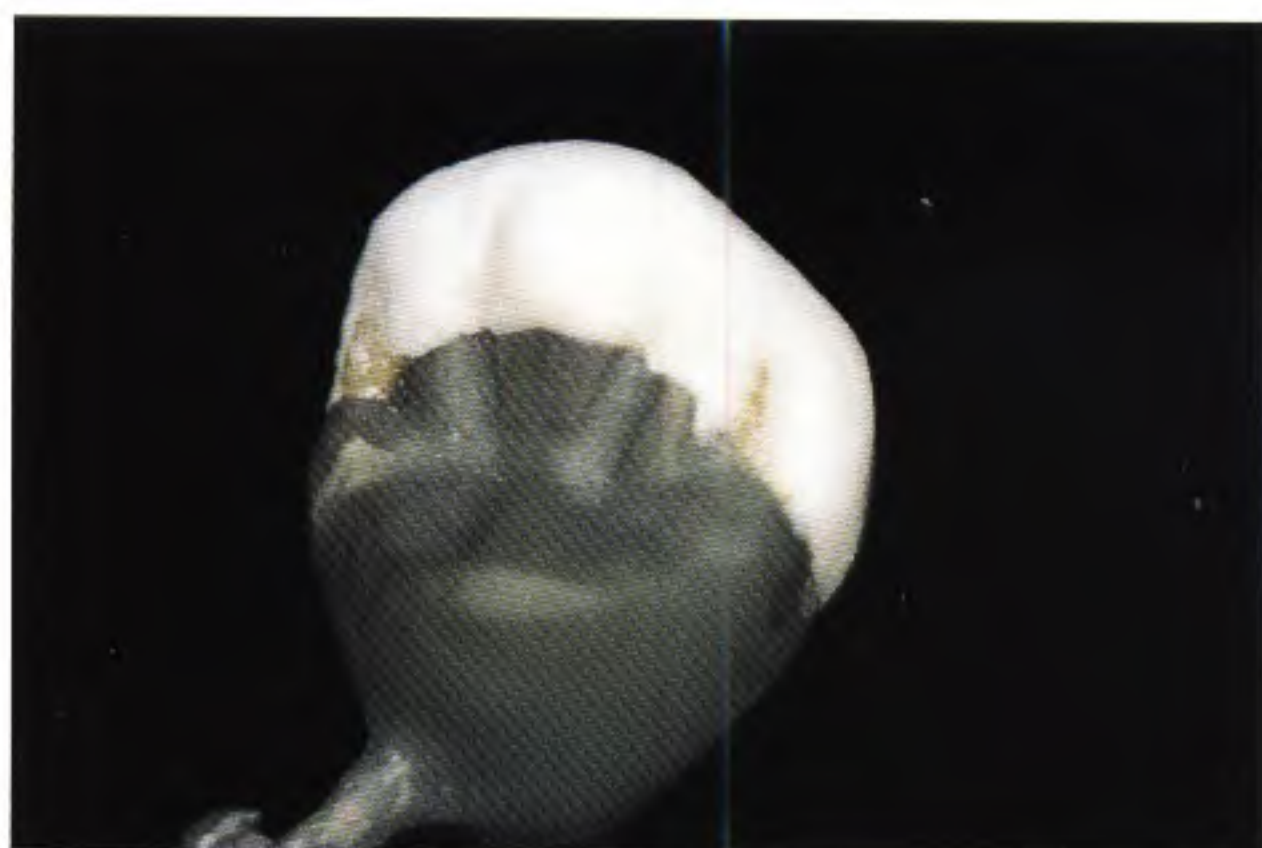


Fig 8-92 Occlusal view of the completed dentin and enamel porcelain buildup.

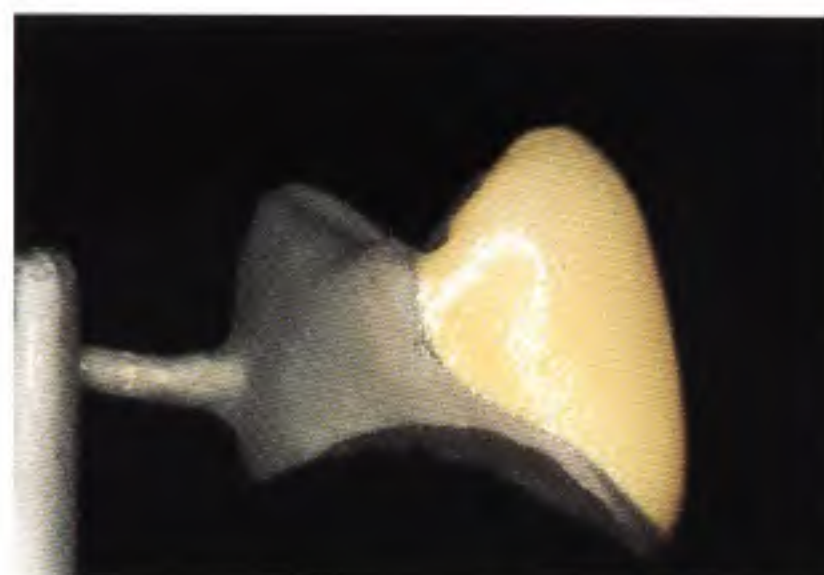


Fig 8-93 Lateral view of crown with opacous dentin after first porcelain firing, demonstrating a subtle, natural blend of colors in the cervical one third from the opacous dentins.

Posterior single crown with porcelain occlusal surface (Figs 8-94 to 8-100)

As indicated previously, the technique for applying porcelain to a posterior crown with either a metal or

porcelain occlusal surface is virtually the same as that used for anterior restorations. However, rather than modify the restoration with opacous dentins during the body buildup, the characterization process can begin at the opaquing stage with opaque modifiers.



Fig 8-94 (left) Wet the oxidized metal substructure (Protocol alloy, Williams Dental Co) with opaque liquid and remove the excess.



Fig 8-95 (right) Lateral view of the coping after the thin layer of opaque porcelain has been fired.



Fig 8-96 Lateral view of coping after the second opaque layer has been fired. Note that some areas still have gray showing through. Invariably, the tendency is not to apply so much opaque on the second application as to cause pooling at the line angles and occlusal surface. The net result can be inadequate opaque coverage.



Fig 8-97 Opaque modifiers are available in a wide array of colors with brands of dental porcelain (Vita VMK 68 Porcelain, Vident). Opaque modifiers are used to internally add more intense color to selected areas of a restoration. Because opaque modifiers are so color intense, mix only small quantities of the particular colors you wish to use. You may dilute the intensity of the color by simply adding more opaque liquid to the mix.



Fig 8-98 Sparingly apply the opaque modifier (Vita 677, Vident) to the cervical region and place a brown modifier (Vita 678) in the interproximal region and occlusal surface. Use the pointed brush to thin the occlusal line. Note that the opaque modifiers on the cervical aspect of the substructure are visible from this occlusal view.

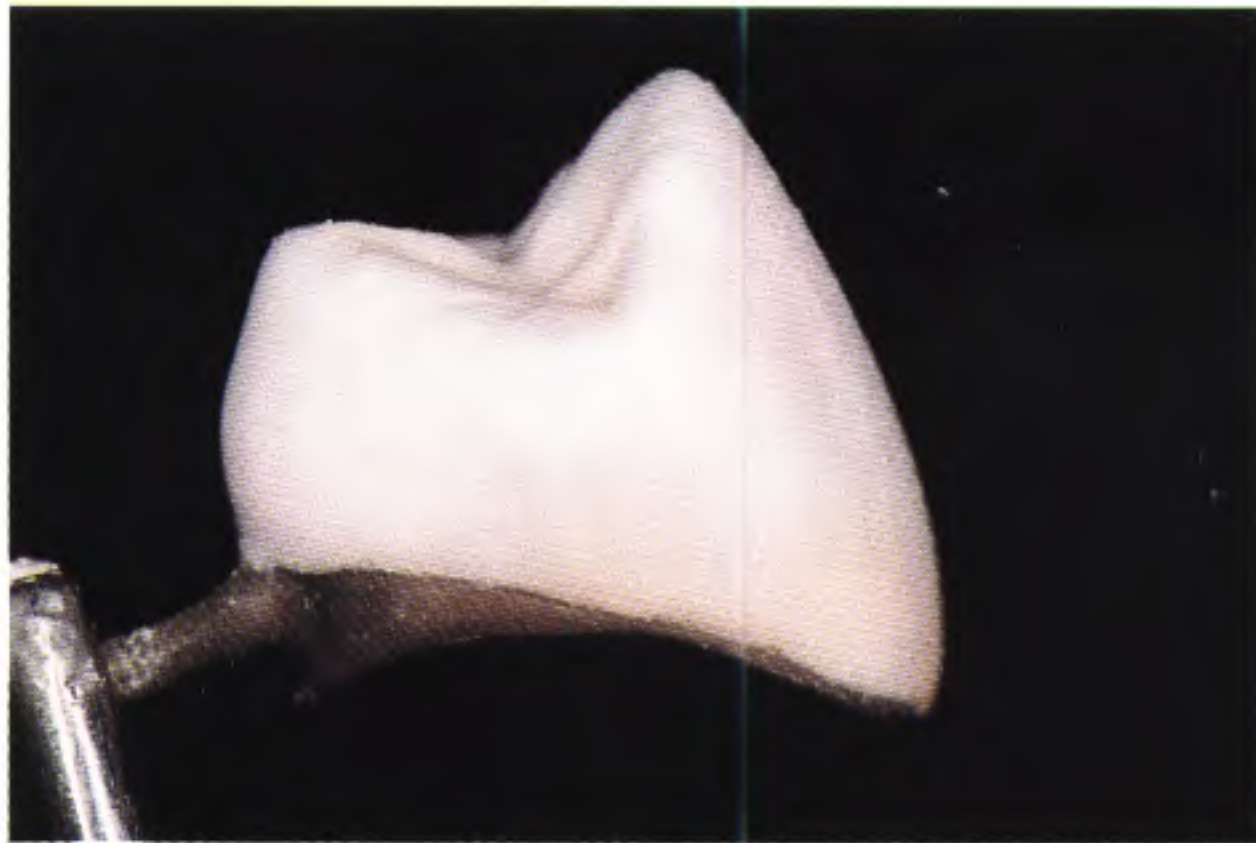


Fig 8-99 Lateral view of the completed buildup. The interproximal additions have been blended into the existing buildup with a whipping brush, and excess porcelain has been removed from the exposed metal collar on the lingual, interproximal, and facial areas.



Fig 8-100 Occlusal view of the restoration after the first body bake. Note that the restoration possesses a close approximation of the proper crown outline form and the development of natural occlusal anatomy.

Now build the restoration to full contour with dentin porcelain. Perform this task on the master cast and use the adjacent teeth to provide a perspective on axial contour and cusp placement. Cut back the dentin porcelain in preparation for enamel porcelain. Apply the enamel and translucent porcelain, if desired, and condense the restoration well. Use a pointed porcelain brush or carving instrument to create the desired occlusal anatomy by sculpting the condensed porcelain. Remove the restoration and apply either enamel or translucent porcelain to the interproximal areas to restore contact.

It is extremely important to make every effort to sculpt the outline form and occlusal anatomy in the condensed porcelain (see Fig 8-99) rather than rely on firing a mass of porcelain on the substructure and "grinding in" the correct anatomy. When time and care are taken to skillfully develop a lifelike restoration in the first body bake, less time will be required for gross adjusting and finishing, thereby minimizing the extent of corrections required for a second bake.

Porcelain application—the fixed partial denture

Anterior fixed partial denture (Figs 8-101 to 8-120)

The procedures involved in adding porcelain to a fixed partial denture differ only slightly but are more complex than those required for a single-unit restoration. You should develop the basic skills required to successfully fabricate a single-unit crown before you attempt multiple-unit restorations.

The opaque porcelain is applied in the same manner as demonstrated with a single-unit crown. But in inexperienced hands, body porcelain may dry out because of the time required to build up multiple units. To help overcome this particular problem, try using a slightly wetter porcelain mixture during initial attempts at multiple-unit cases.

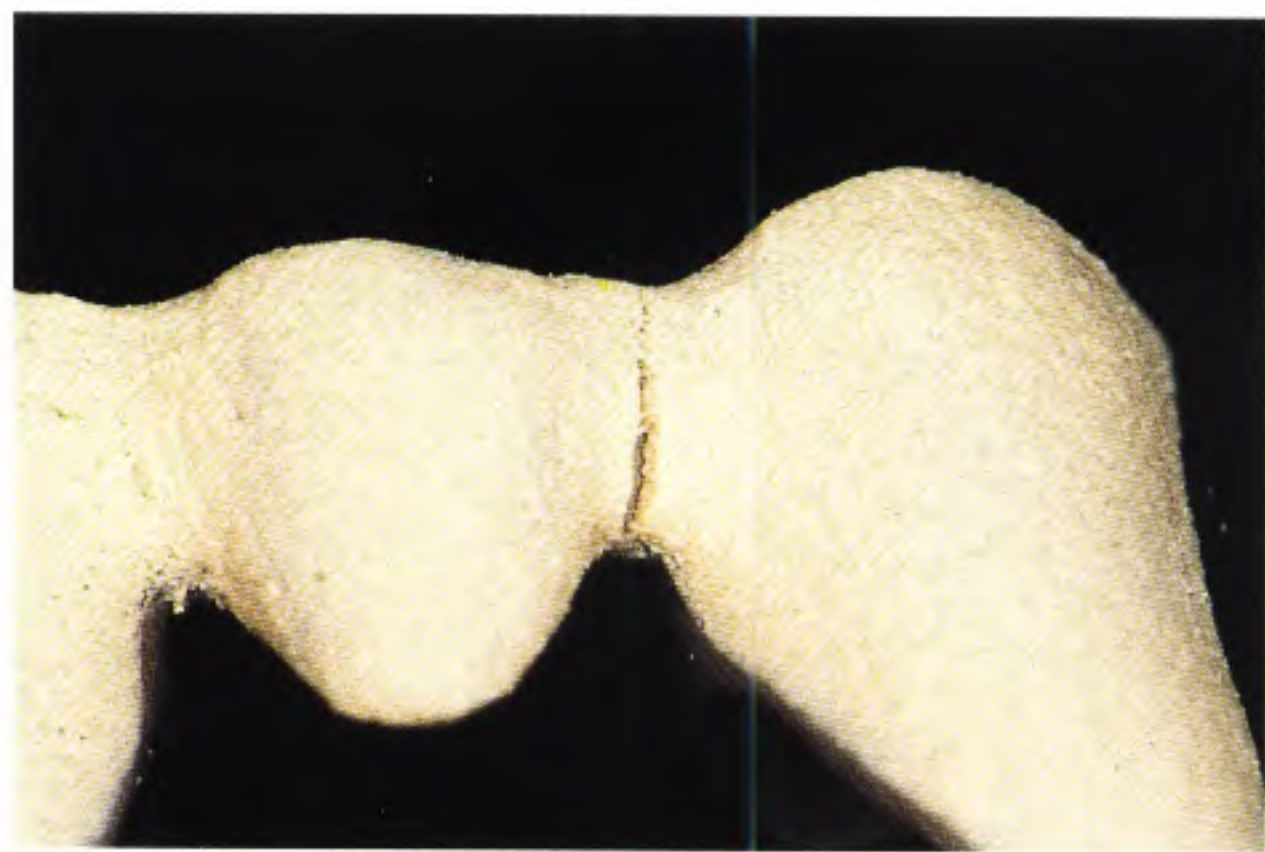


Fig 8-101 Inspect the framework after the first layer of opaque porcelain has been applied and fired. With multiple-unit cases there is a greater likelihood that several porcelain applications will be necessary. Cracking on the facial surface in the connector area is not uncommon, particularly if the fixed partial denture has been pre-soldered.



Fig 8-102 Apply and condense additional opaque porcelain into the crack in the connector area, cover any gray areas, and fire the prosthesis a second time.



Fig 8-103 Return the opaqued fixed partial denture to the master cast with a piece of tissue paper cut to cover the entire pontic region and placed over the labial surface of the gypsum cast. The tissue paper will prevent porcelain from sticking to the cast. Instead of using tissue paper, the edentulous area can be sealed with cyanoacrylate or lubricated with a porcelain releasing agent. Moisten the tissue paper with a drop or two of distilled water. The tissue should be completely wetted and should cling to the edentulous ridge.



Fig 8-104 Next, add a small portion of dentin porcelain to the underside of the pontic on the fixed partial denture framework. Use the pointed porcelain brush to move the porcelain over the opaqued surface and completely cover the tissue side of the pontic.



Fig 8-105 Return the framework to the master cast and gently rock it back and forth until it seats completely. Remove the framework and inspect the tissue side of the pontic. This area should be covered completely with porcelain and be well condensed. This is usually a fairly fragile part of the buildup, so initially you may wish to fill in any voids, knowing that the gingival extension of the pontic is certain to require a subsequent correction bake. Some ceramists choose to slightly overbuild the pontic to compensate for shrinkage and then "grind in" the tissue contact on the working cast after firing (see chapter 9).

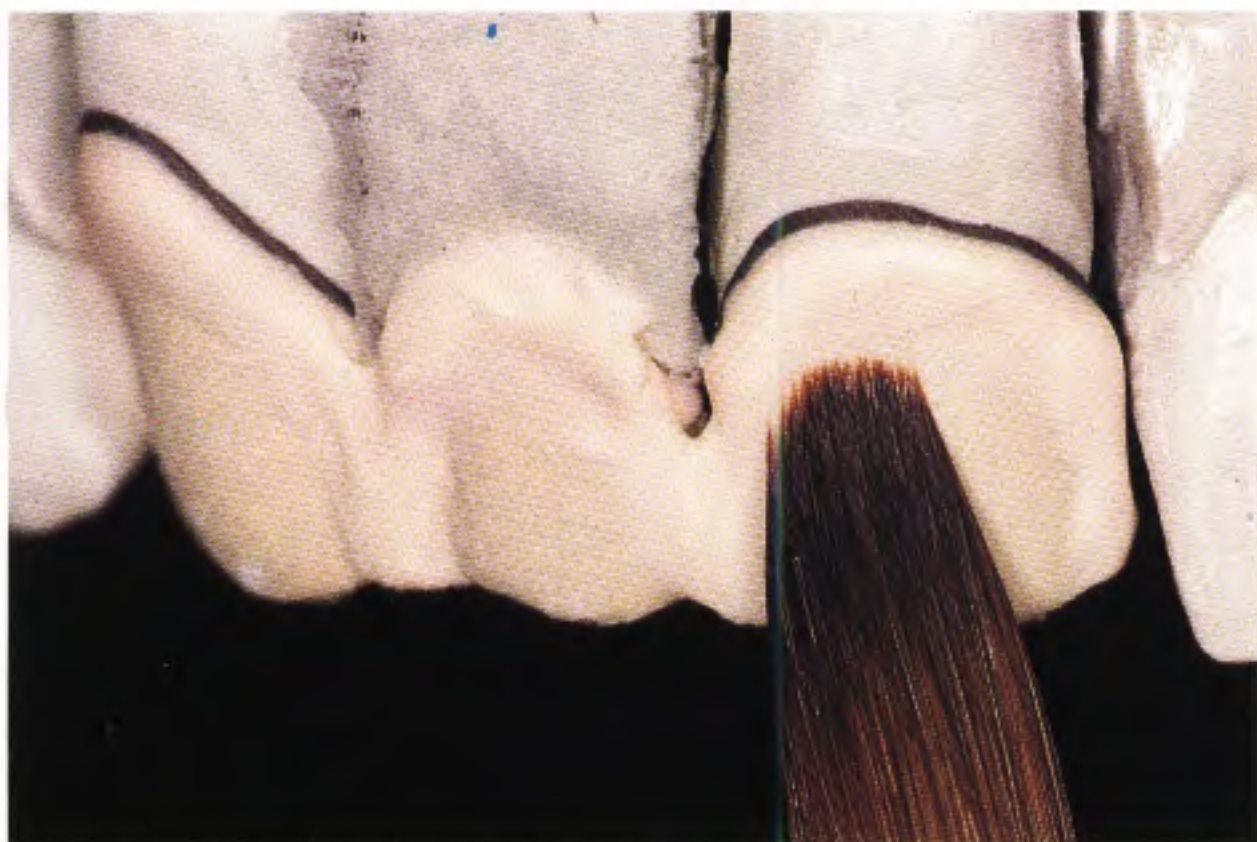


Fig 8-106 Place the framework back on the master cast and apply dentin porcelain or add and condense opacous dentin to the cervical areas of the three components.

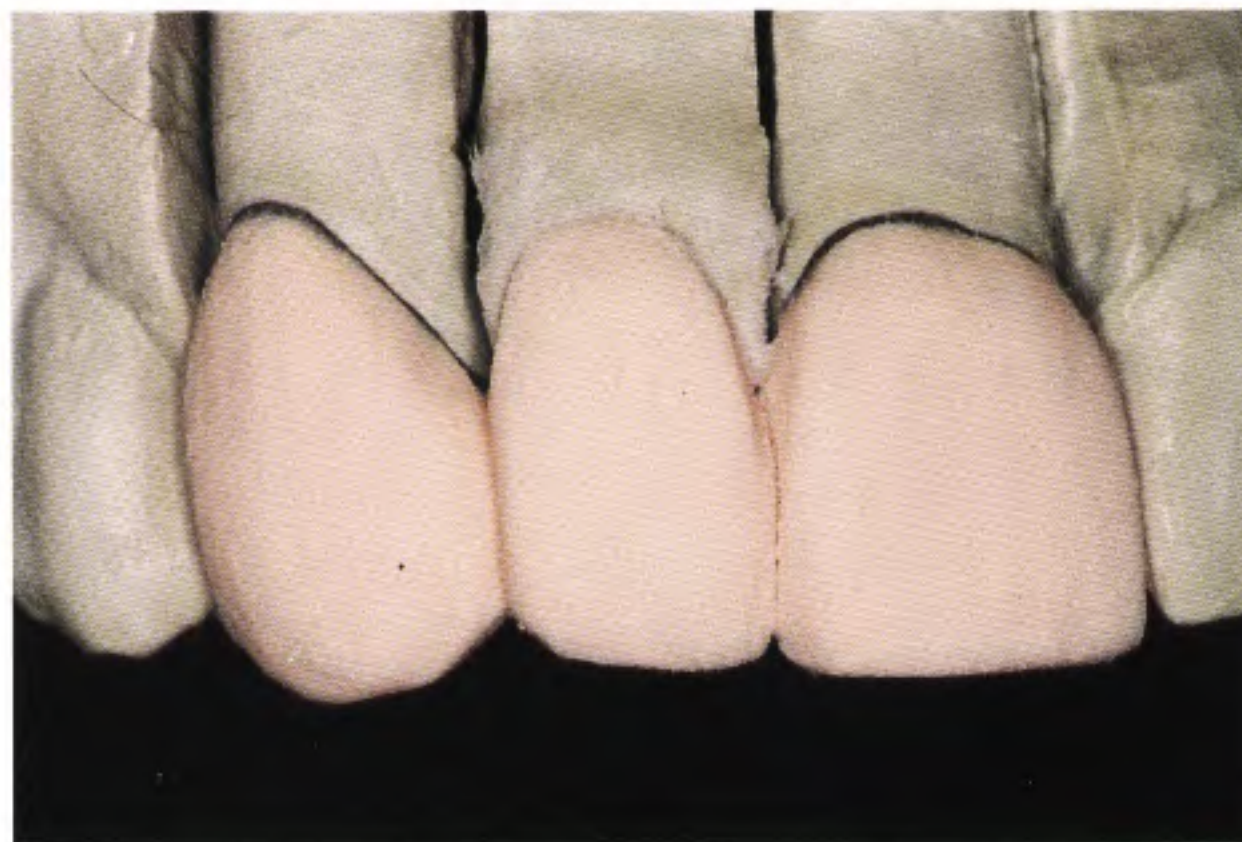


Fig 8-107 Complete the dentin buildup.



Fig 8-108 Create the developmental lobes, if desired. Use a thin razor knife to cut through the interproximal areas and individualize the teeth.



Fig 8-109 Add the enamel veneer with a standard buildup or a lateral segmental buildup technique.



Fig 8-110 Condense the porcelain buildup with a small mallet or use another technique of your choosing.



Fig 8-111 Measure the mesial-distal width of each tooth with a Boley gauge.

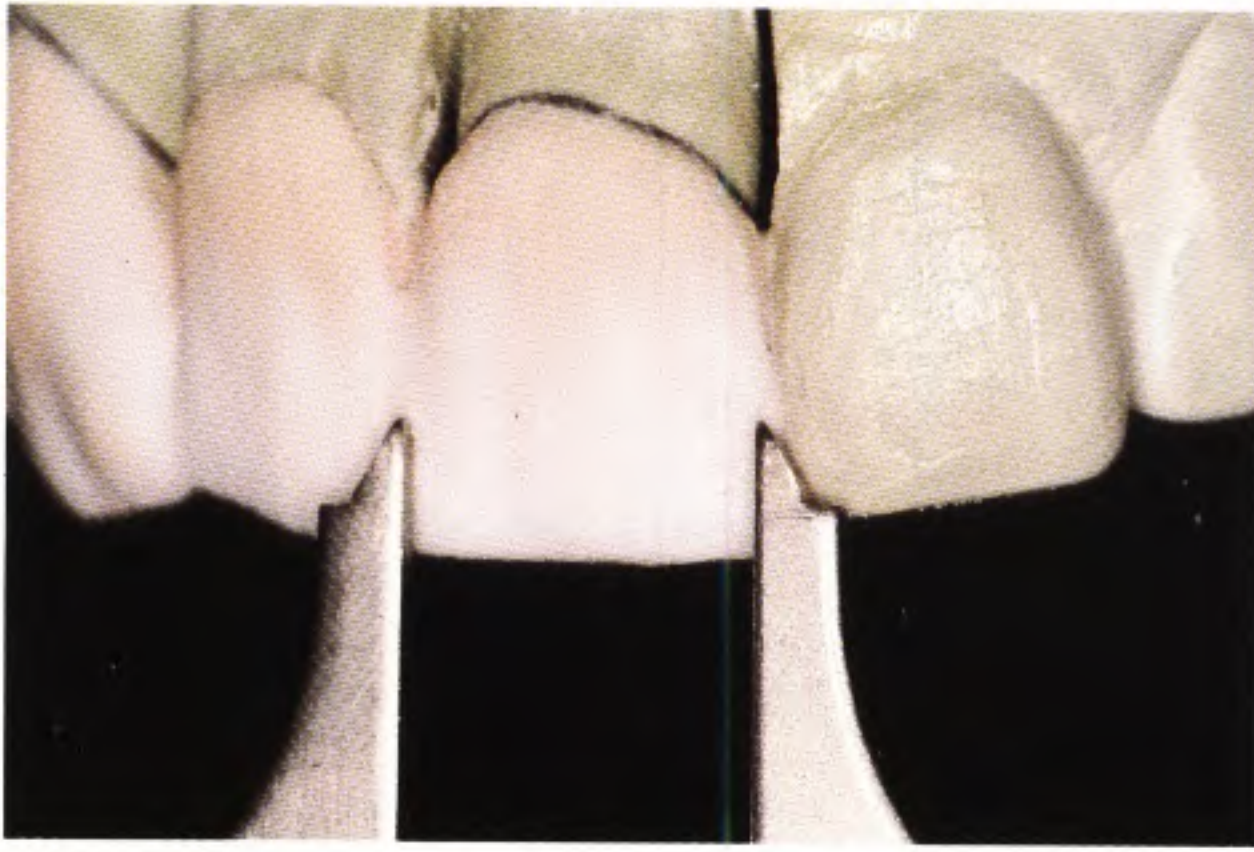


Fig 8-112 Compare that measurement with the porcelain buildup. It is important to verify a correction estimation of each tooth's width before firing and to make certain the buildup is constructed to allow for the average shrinkage of the porcelain.

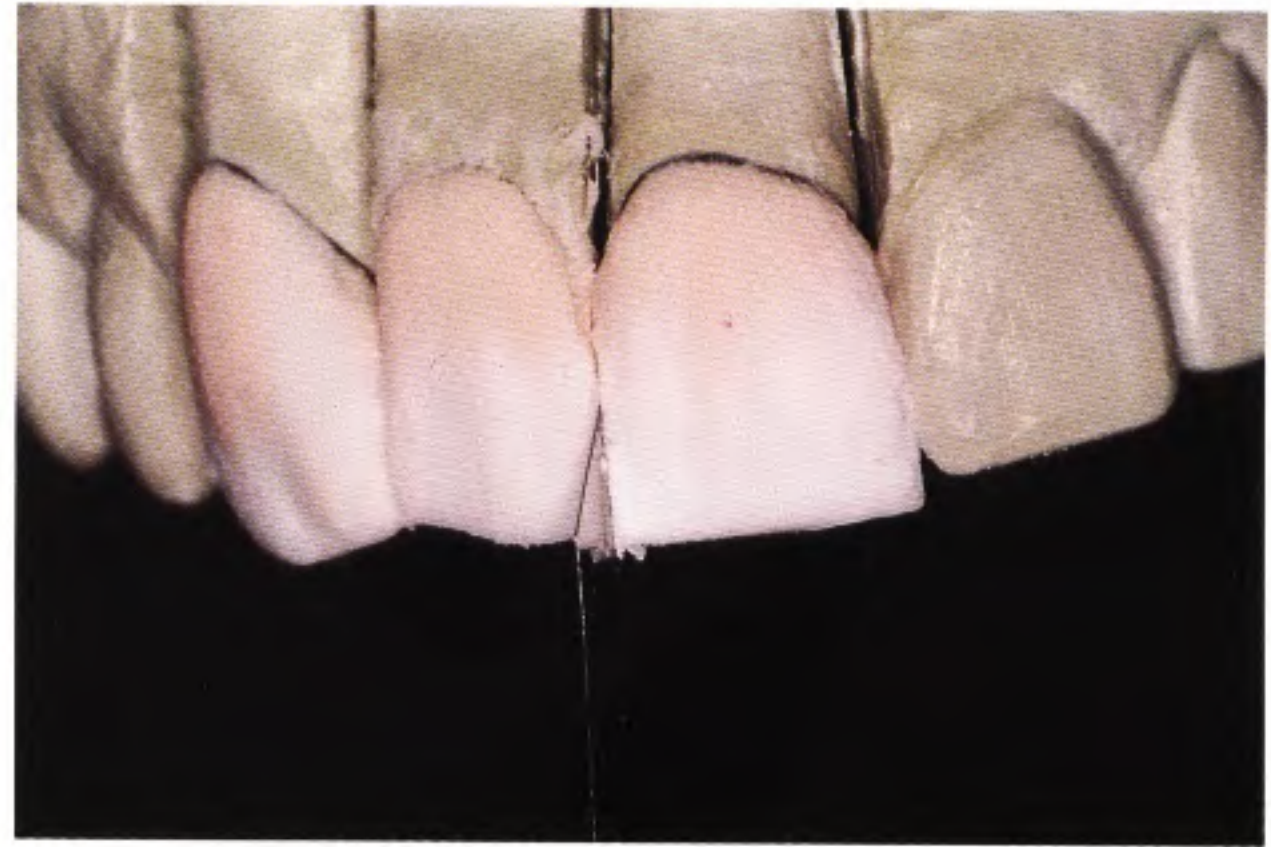


Fig 8-113 Use a knife or other instrument to make any necessary adjustments in the mesial-distal width. Porcelain shrinks toward bulk, so individualizing the three teeth will allow each to fire separately and minimize the amount of interproximal cracking (tearing). During the first body bake, tears may appear in the area of the connector areas due to firing shrinkage. To avoid this, use the thin razor knife to cut completely down to the opaque porcelain layer.



Fig 8-114 When interproximal cuts are made they should be thin to delicately establish the interproximal line angles. In this way, the natural contours of these regions are not destroyed but are preserved. As you gain experience, you will learn how to compensate for this interproximal shrinkage through selective condensation of the initial porcelain layer in the embrasures themselves. When attempting to avoid interproximal tearing and thus possibly accomplishing the porcelain application in one firing, interproximal cuts are not made. Clean the lingual metal surface of any excess porcelain.

Before firing, carefully remove the prosthesis from the master cast and examine it thoroughly from the facial and lingual aspects. Moistening of the adjacent stone teeth and the tissue that is underneath the pontic may

facilitate removal of the restoration. If the porcelain has dried and is sticking to the cast in any of these areas, wet the adjacent portions of the gypsum cast; this usually allows the porcelain to be released.



Fig 8-115 (left) Facial view of the porcelain buildup.



Fig 8-116 (right) Lingual view of the porcelain buildup.

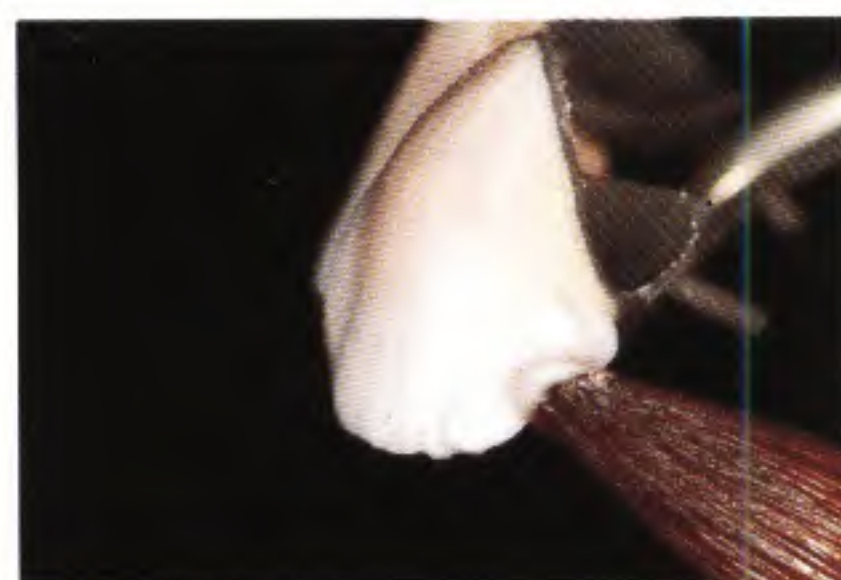


Fig 8-117 (left) As a final step, add enamel or translucent porcelain to the interproximal contact areas and blend the additions into the existing contour.



Fig 8-118 (right) Place the restoration on an appropriate saggar tray. Be careful to properly balance the framework on the pegs, because many anterior fixed partial dentures have a tendency to tip labially due to their arch form. Obviously, a great deal of work can be lost very quickly if the unfired restoration falls off the pegs.



Fig 8-119 Labial view of the three-unit fixed partial denture after the first bake. Notice that in this case the interproximal cuts were made and the embrasure between the canine and lateral incisor opened during firing. Yet the same area between the central and lateral incisors retained a more natural appearance. The fired porcelain possesses an orange peel surface, indicating the firing schedule used was correct for this particular porcelain.



Fig 8-120 Lingual view of the prosthesis. The porcelain was well condensed along the porcelain-metal junction and did not pull away from the metal substructure. The incisal edge reflects the layering of porcelain blends of enamel and translucent porcelain. The obvious separation in the canine interproximal region alone will necessitate the addition of a second application of porcelain. It is also possible that other portions of the prosthesis will require modifications. Rather than subject the prosthesis to unnecessary multiple firings, proceed to chapter 9 for a discussion of adjusting and finishing techniques.

Summary

This chapter has presented the basic techniques that can be used to apply opaque and body porcelain to an oxidized metal substructure. In addition to presenting examples of several anterior and posterior substructure designs, the standard and lateral segmental buildup techniques have been presented. For an added challenge, an anterior three-unit fixed partial denture was included to tax your talents once you

have mastered the skills needed to construct a satisfactory single-unit anterior and posterior restoration. The basics of internal color development were introduced through examples of opacous dentins and opaque modifiers.

Move on to chapter 9 for guidance on how to adjust and finish these fired porcelain restorations in preparation for second, correction bakes, characterization (staining and glazing), and the final polish.

Adjusting and Finishing the Metal Ceramic Restoration

Introduction

Applying and firing the porcelain veneer to a metal substructure only approximates the shape, contour, occlusion, and surface finish of the final restoration. The very nature of the porcelain application process, with its requirement to slightly overbuild the ceramic, can result in a bulky (overcontoured) restoration. Even when you exercise great care, anatomically correct axial line angles and the final surface texture are difficult to achieve. Consequently, the fired porcelain requires additional adjustments to reduce any overcontouring and re-create a lifelike ceramic surface finish before the characterizing (staining) and glazing stages.

Adjusting, contouring, and finishing procedures for metal ceramic restorations play a critical role in achieving both proper function and optimal esthetics. Occasionally these tasks are viewed as mundane; however, anyone who has carefully observed an accomplished ceramist at work realizes that it is during these final phases of the fabrication process that a restoration comes to life. Subtle changes in contouring, surface texture, and characterization (staining) often make the critical difference between a mediocre and an exceptionally finished restoration. Surprisingly, little equipment and few instruments are needed for the finishing procedures. When it comes to adjusting and contouring, knowing what to do and how to do it may be more important than what you do it with.

Armamentarium

As with metal preparation, the simplest way to describe an appropriate armamentarium for adjusting and finishing is to divide that armamentarium into three categories: (1) equipment, (2) instruments, and (3) materials (see Appendix E). These items can be used to adjust and finish both the dental porcelain veneer and the metal substructure.

Equipment

Like many laboratory procedures, a wide variety of sophisticated equipment is available for individuals interested in equipping either a commercial dental laboratory or a small laboratory in a dental office. Many of these items are essential to a basic operation; others are highly recommended. Several of the more important pieces of equipment that can lead to improved quality or facilitate production are listed in Appendix E. When cost is a limiting factor, develop a budget and a long-term plan to complete your acquisition of this equipment within a realistic timeframe.

As indicated in chapter 7, a laboratory microscope makes your adjustments much more precise and saves many hours of work. After using a microscope for a short period of time, you will probably consider it one of the most essential tools in the dental laboratory.

Almost any type of dental handpiece may be used to contour a porcelain restoration; however, some handpieces have been designed for this specific purpose and will increase the probability of success. Select a variable-speed handpiece with speeds of 50,000 rpm or below, because it can be used for most adjusting and polishing procedures. High-speed air-driven handpieces that turn at speeds over 50,000 rpm are normally used for fine detail work such as sculpturing porcelain occlusal surfaces. They have the ability to generate potentially damaging heat to the ceramic buildup, create internal stresses, and produce microcracks in the fired porcelain. Therefore, light pressure should always be used and you should avoid holding the abrasive in one place for a prolonged period of time.

Instruments

The principal instruments needed for the adjusting procedures are gauges used to measure the length, width, or thickness of any given tooth or restoration



Fig 9-1 The Iwanson metal calipers (Pfingst Co) can be used for thickness measurements of metal or metal and porcelain to a tolerance of approximately 0.1 mm.



Fig 9-2 Diamond abrasive instruments are available in a variety of shapes, sizes, and grits, making them useful for all phases of adjusting and finishing.

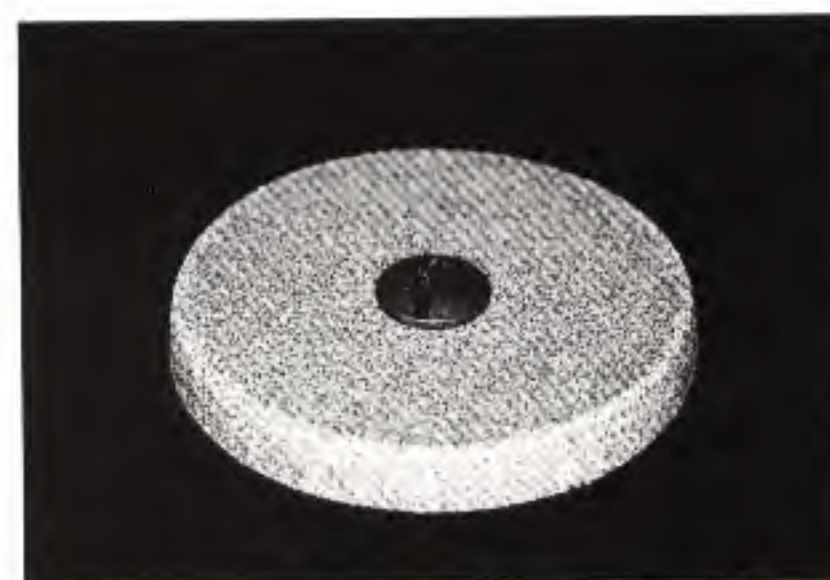


Fig 9-3 The Vident Porcelain Pre-Polish Wheel (Vident) is gray in color and looks similar to a heatless stone but is designed for smoothing and polishing ceramic surfaces. The Vident Final Polish Wheels are a distinctive pink color.

(see Appendix E). Several measurement gauges will also ensure the accuracy of the restoration and decrease the amount of time required for contouring. For gross measurements (greater than 1.0 mm), use a metal caliper such as a Boley gauge. For a finer scale, an Iwanson metal calipers (Pfingst Co) is recommended to measure the thickness of metal or metal and porcelain to within approximately 0.1 mm (Fig 9-1).

Materials

A large selection of rotary finishing instruments are available for contouring. For the initial gross reduction, use either a diamond or stone specifically designed for porcelain. These instruments were intended for use at slow to medium speeds and are available in various sizes. Care should be taken with very coarse abrasives, because they tend to chip and crack the fired porcelain. Diamond abrasives are available in many different shapes and grits to cover all levels of finishing, from gross reduction to final contouring (Fig 9-2). Finer abrasives such as white stones can be purchased separately or in porcelain adjustment kits. Prepolish wheels are designed for smoothing and polishing ceramic surfaces and can also be used (Fig 9-3).

For fixed partial dentures, diamond disks are recommended for shaping and contouring the interproximal areas between a pontic and its adjacent retainer (Fig 9-4). Diamond disks are available in a variety of configurations (notched, unnotched, single-sided or double-sided diamond coated, large to small, etc). They may be rigid or ultra-thin (0.1 mm in thickness). Generally, the thinner these abrasive disks, the better.

The choice of abrasives for creating surface texture will depend on the needs of each individual restora-

tion. Some cases will require a level of surface texture best re-created with a coarse diamond instrument; others will demand an extremely smooth and glossy finish established with porcelain prepolishing wheels and mechanical polishing. In the case of metal ceramic crowns with porcelain labial margins, the ceramic margin is best finished with diamond prepolishing wheels. Experience has shown that even the finest stone or sandpaper disks are capable of fracturing the delicate porcelain.

Regardless of the composition and shape of the stones for ceramic materials, they should be clean and dedicated for use only with porcelain, not with metal finishing. To avoid the possibility of contamination of both metal and porcelain, abrasives should be dedicated to either one application or the other. Invariably, small particles of metal produced during metal grinding will find their way into the ceramic veneer and discolor the porcelain surface or appear as a physical contaminant in the fired porcelain. Even if the stones have been used previously on acrylic resin, or any other material for that matter, residual particles may be transferred to the surface of the porcelain and appear as a black speck (Fig 9-5). Therefore, separate the porcelain finishing materials from the metal finishing and polishing items and do not intermix the two.

Many of the disclosing media mentioned in chapter 7 may be used in contouring and finishing procedures and greatly add to the accuracy of the final restoration. To ensure that the interproximal and occlusal/incisal contacts on a restoration or cast are as close as possible to the patient's, use only the thinnest of materials. Because the restoration must be placed on its die and returned to the master cast, do not hesitate to use a disclosing medium, such as Occlude (Pascal Co), AccuFilm IV (Parkell), or Crown Fit Seating Indicator (Belle de St Claire) to verify complete seating.

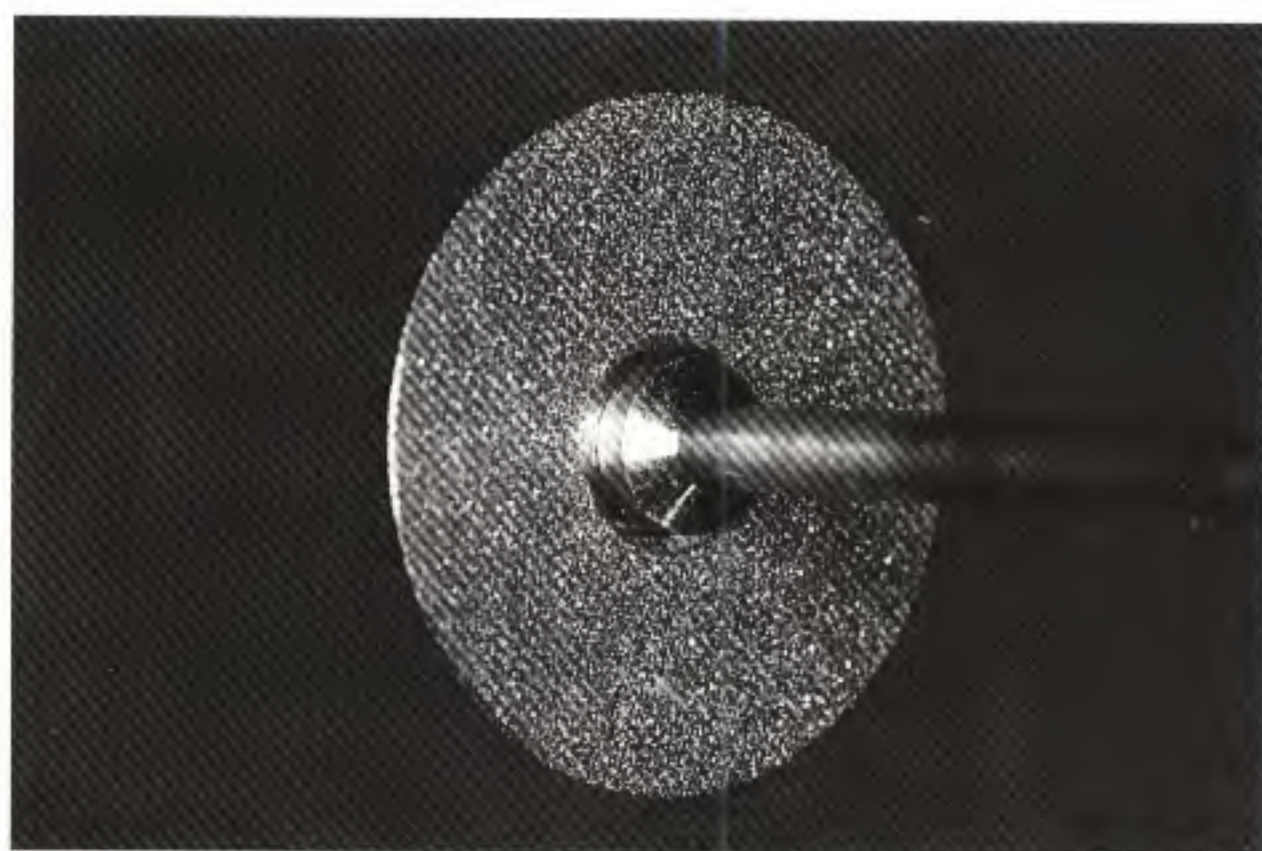


Fig 9-4 (above) Diamond disks are recommended for adjusting and contouring interproximal areas and are offered in several grit sizes, in both ridge and flexible form, both single and double-sided diamond coated (Horico disk, Pfingst Co, shown).

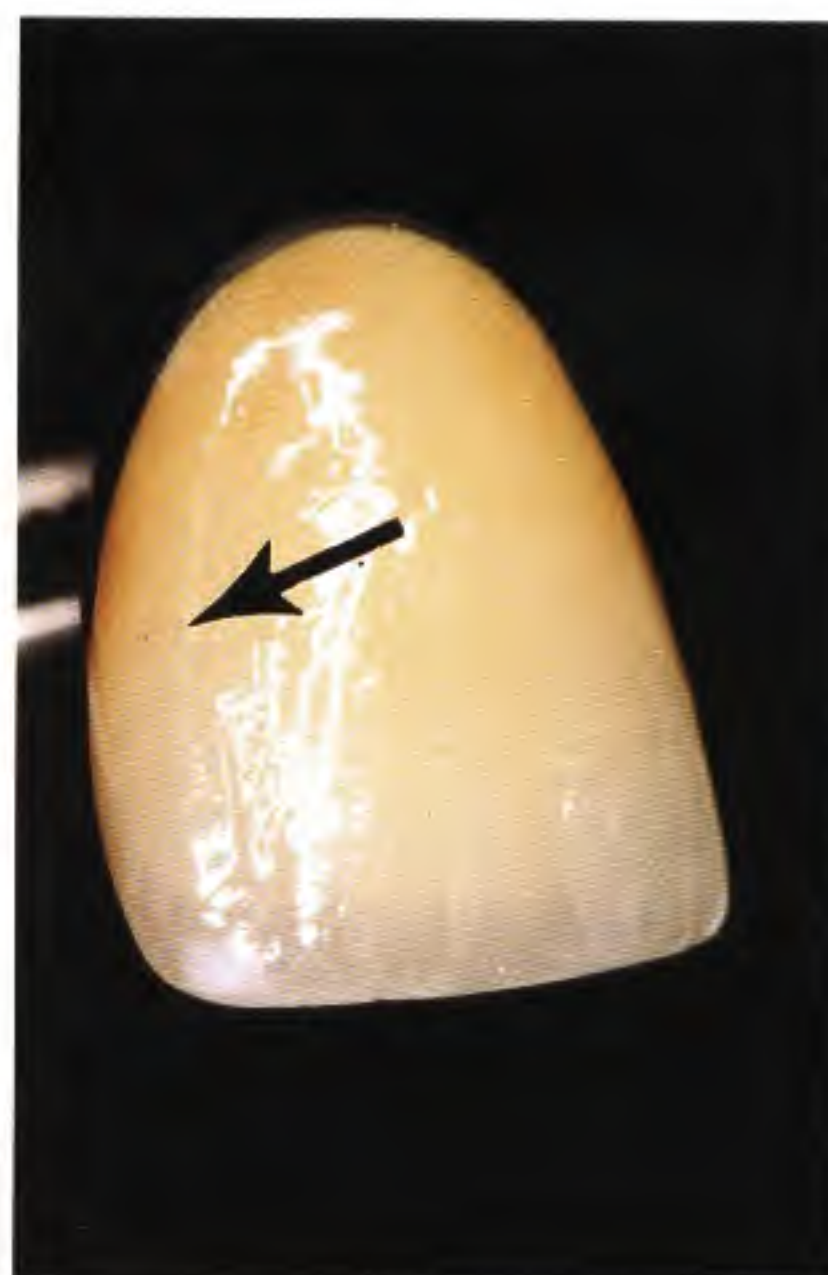


Fig 9-5 (right) Glazed porcelain surface contaminated with metal debris (arrow) appearing as a dark speck.

Other materials that will be needed include a disclosing medium or an articulating film, such as AccuFilm II (Parkell), for adjusting interproximal and occlusal contacts. Avoid using articulating papers as they are generally thick (up to 50 μm) and prone to giving false markings.

One of the best products to use in the final check of the interproximal and occlusal contacts is Artus Occlusal Registration Strips (Artus Corp), often referred to as shimstock. This material is roughly 12 μm thick and can be used by the dentist when fitting the restoration in the mouth. Using the same indicating materials in the laboratory that are used in the mouth will ensure a much more accurate restoration and decrease the insertion time for the dentist.

Anterior single crown with metal lingual surface

Seating the die

The first step in contouring a metal ceramic restoration is to ensure that the casting (metal substructure) seats completely on the die. Even when great care is taken during the porcelain application procedure, small particles of porcelain powder can find their way inside the restoration and prevent seating of the work; therefore, carefully inspect the intaglio (internal)

surface of the crown for porcelain residue. Do not rely exclusively on a gross visual examination—use a microscope or some other form of magnification when inspecting the inside of the casting. Remember, particles of translucent porcelain will appear clear when fired and may not be detectable to the naked eye. When it is necessary to remove porcelain debris, use a small diamond or stone, or simply air-abrade the area with 50- μm aluminum oxide. If you have a second die, coat it with Crown Fit or AccuFilm IV to expedite refitting the restoration.

Once the refitting is complete, remove the die from the master cast and confirm the fit of the restoration by gently seating the casting on that die (Fig 9-6) before returning the die to the master cast. Do not proceed with the adjusting and contouring without taking the time to verify the complete seating of the restoration. If the interproximal and occlusal contacts are overcontoured, the restoration is unlikely to seat completely in the patient's mouth.

Adjusting the interproximal contacts

With the die in the master cast, position the restoration in its anatomically correct relationship to the adjacent teeth, if present. If it fails to seat for any reason, do not force it to place. Incomplete seating could be due to one or both of the interproximal contacts being overcontoured. Ideally, the master cast should be designed so the adjacent stone teeth are removable.



Fig 9-6 The restoration is returned to the master die to confirm complete seating and a proper fit.

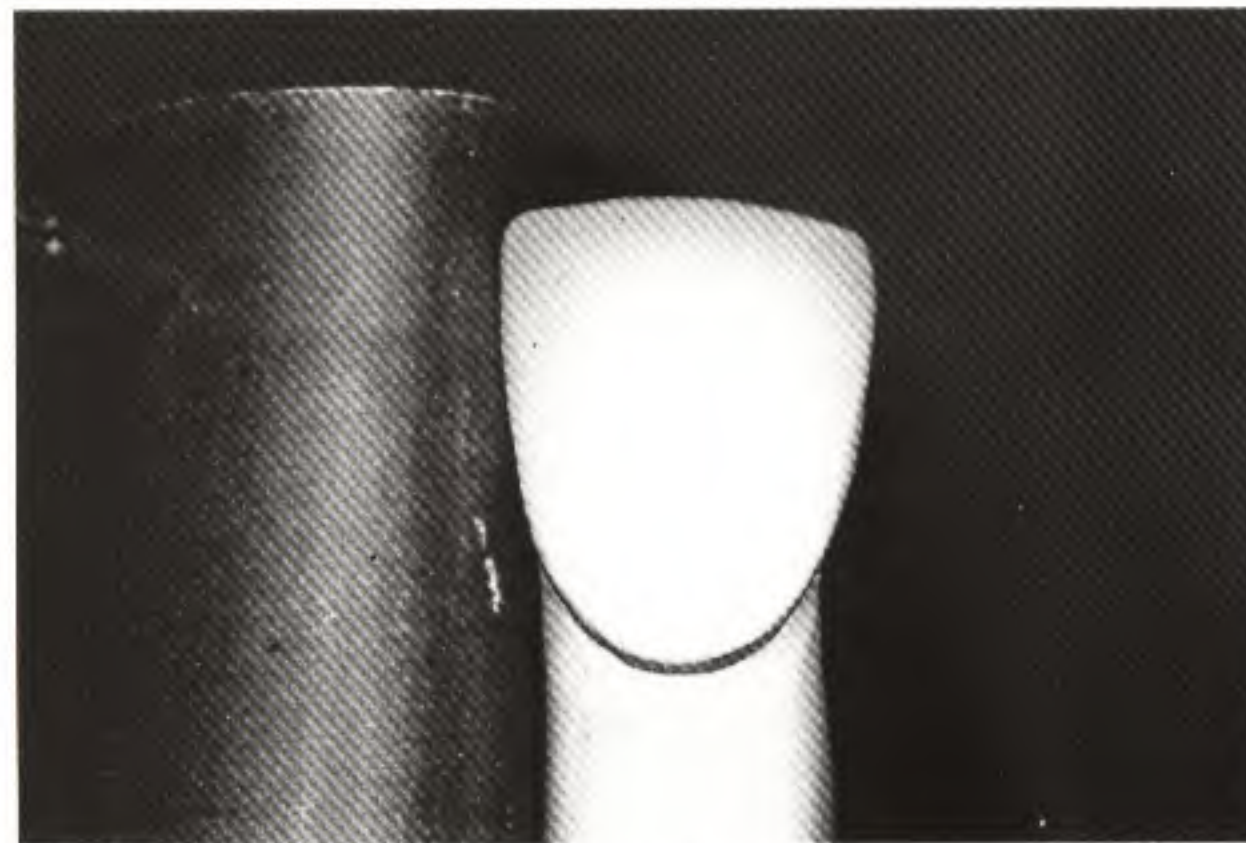


Fig 9-7 Remove the die distal to the restoration and mark the mesial interproximal contact using thin double-sided marking film (AccuFilm, Parkell shown) or some other disclosing medium.



Fig 9-8 Remove the restoration from the master cast and note how the marking material identifies the location and intensity of the contact (*area in red*).



Fig 9-9 Hold the restoration securely, protect the metal margins, and make the necessary adjustments to the contact area. If gross reductions are necessary, select a coarse abrasive. Otherwise, use a Vident Pre-Polish Wheel (shown) or Vident Final Polish Wheel for minor adjustments.

With the tooth distal to the crown removed, place a thin double-sided marking film (AccuFilm) or one of the disclosing liquids or sprays on the remaining interproximal areas and reseal the crown (Fig 9-7). Remove the restoration from the cast. The AccuFilm should have transferred a marking to the restoration, indicating the location and intensity of the contact (Fig 9-8).

If the adjustment is extensive, it may be necessary to recontour the area with a coarse abrasive; otherwise, use a porcelain prepolishing or final polishing wheel (see Appendix E). Hold the restoration securely in one hand (protecting the margins), and lightly go over the area marked by the film (Fig 9-9).

As the contact area approaches the appropriate position and intensity, make the adjustments with a very fine abrasive, such as a diamond prepolishing wheel. In this way, once that contact area is developed it will not only be anatomically correct but also smooth.

The porcelain prepolishing wheel makes the necessary correction and leaves behind a smooth ceramic surface. In order to avoid an overreduction, adjust one interproximal contact area at a time. After perfecting the mesial contact area, repeat the procedure on the distal contact, first without, then with the adjacent stone teeth in place (Fig 9-10).

If for some reason you find that additional porcelain is required on one of the contacts, proceed with the

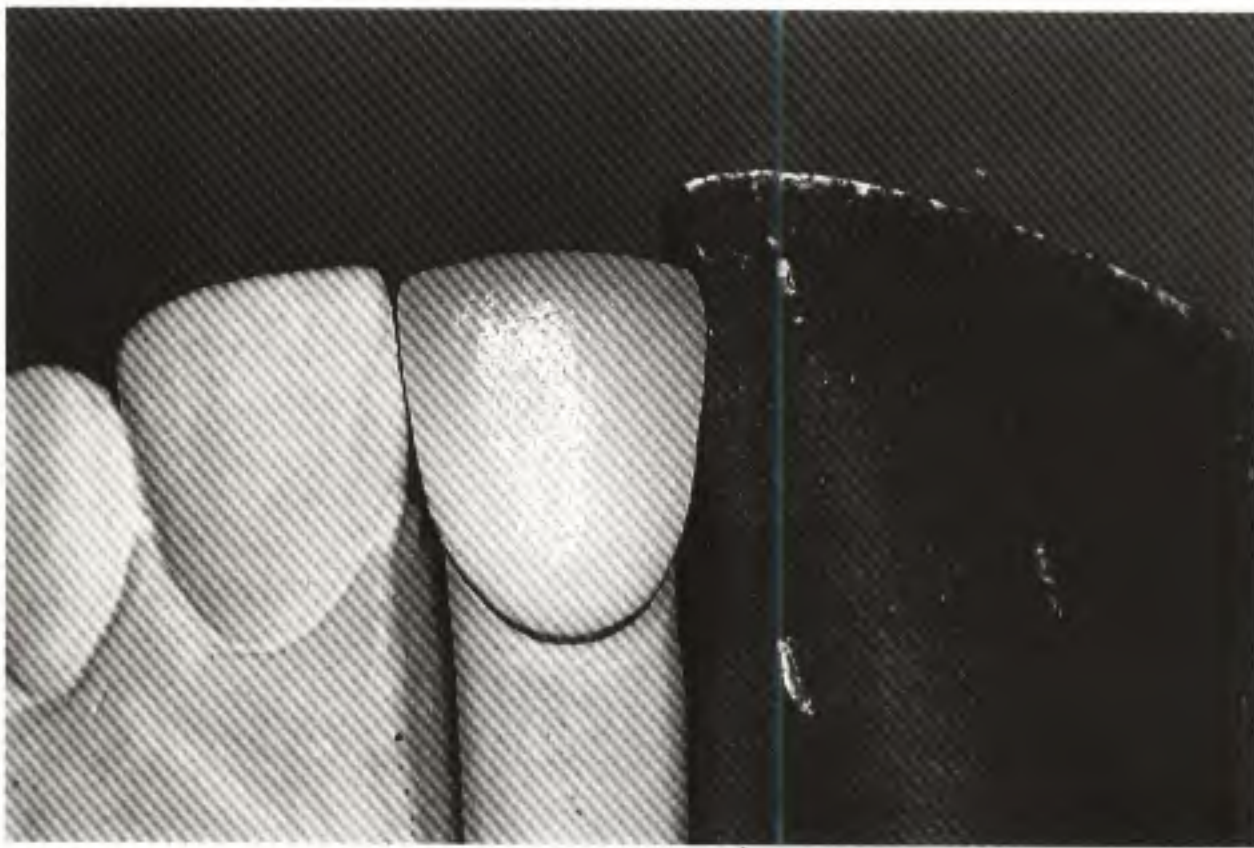


Fig 9-10 Return the distal die to the master cast then make and adjust the distal interproximal contact area.

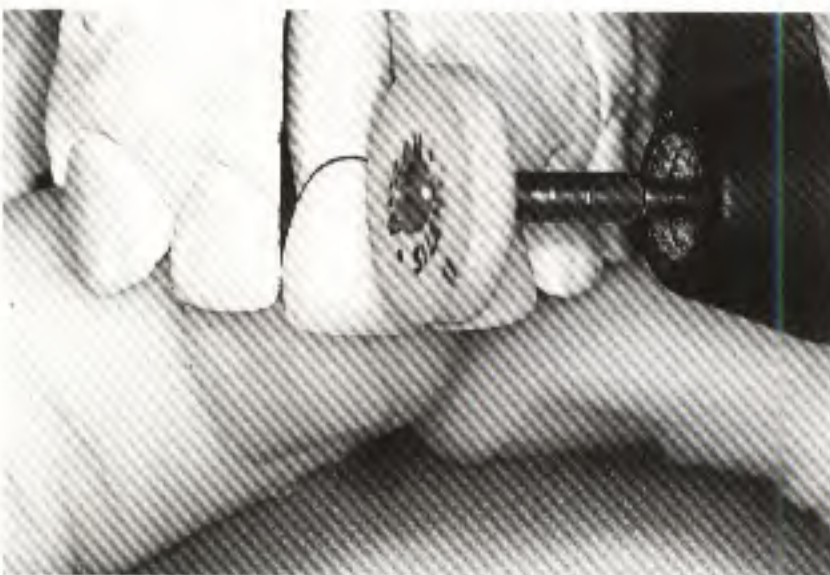


Fig 9-11 Adjust the axial contours of the facial surface using a Busch Silent Stone (shown) or a straight shank diamond instrument (see Fig 9-2). Use the contralateral tooth, the maxillary left central incisor, as a guide for contour and surface texture.



Fig 9-12 Once the initial (gross) reduction of the first body bake is completed, carefully examine the restoration for areas in need of correction. In this case, the mesioincisal corner and remainder of the incisal edge need to be lengthened. These and any other changes will be made in a second, corrective body bake.

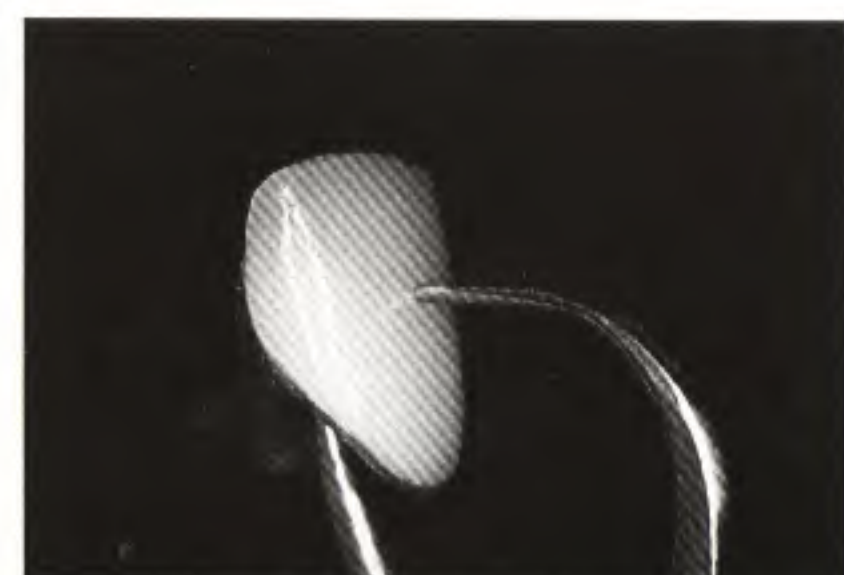


Fig 9-13 Periodically check the thickness of the restoration to ensure that it is not over- or undercontoured.

finishing procedure. You may find that other areas will require additions or correction, and they can all be remedied by a second bake.

Initial contouring of the facial surface

After the restoration has been seated on the working cast, its overall shape and contour can be carefully evaluated. Any under- or overcontoured areas should be identified so they may be corrected in an additional application of porcelain and a second body bake.

Begin by adjusting the axial contours with a straight shank diamond cutting instrument or Busch Silent Stone mounted in the slow-speed handpiece (Fig 9-11). Use the same tooth on the contralateral side of the arch as your guide for proper shape, contour, and surface texture if it is unrestored (Fig 9-12). For most patients, the two teeth will be mirror images of one another. In the event the mesial and distal widths are

not the same, the height of contour can be adjusted to give the illusion that both teeth are the same size.

Adjust the lingual concavity and incisal edge. Be sure to periodically check the thickness of the restoration using your Iwanson gauge (Fig 9-13). Remember, the minimum thickness of the restoration is 1.3 to 1.5 mm for both metal and porcelain. Measurements less than these dimensions may result in an undesirable shade.

Second porcelain application and body bake

The fitting of the interproximal areas and the initial (or gross) reduction of the facial surface should be accomplished quickly. From these two procedures alone, you should be aware of what areas of the restoration are undercontoured or deficient, as is the case of the mesioincisal corner and incisal edge of the crown in Fig 9-12. Use this second porcelain



Fig 9-14 The restoration should be cleaned to prepare it for the second application of porcelain. Air-abrade the porcelain-bearing surface with 50- μ m aluminum oxide, and then steam clean or ultrasonically clean the crown to remove any aluminum oxide or debris from the adjustment procedures.



Fig 9-15 Apply dentin and enamel porcelain to those areas to be corrected. Condense the porcelain well.



Fig 9-16 Examine the facial surface to ensure that the desired contour has been established. Inspect the lingual surface, the metal collar (if present), and the internal aspect of the crown and remove any excess porcelain from these areas before firing.



Fig 9-17 Adjust the porcelain firing schedule according to the porcelain manufacturer's recommendations for a second body bake. The fired porcelain should have a glossy or an "orange peel" appearance.

application to correct these deficiencies with one bake, so you can proceed to final finishing and complete the restoration with a minimal number of firings. The remaining procedures are detailed in Figs 9-14 to 9-17.

Perfecting interproximal contacts

Although you already adjusted the interproximal contact areas in your initial adjustment, the restoration has received an additional application of porcelain. In

the process of making these necessary corrections, the interproximal contact areas may have been involved. Therefore, it is wise to recheck the interproximal areas to ensure complete seating on the master cast (Fig 9-18). The procedure is the same as described previously.

Final contouring of the facial surface

Keep in mind that the adjusting procedures performed at this point involve a serial polishing process: you begin with a coarse instrument for contouring and

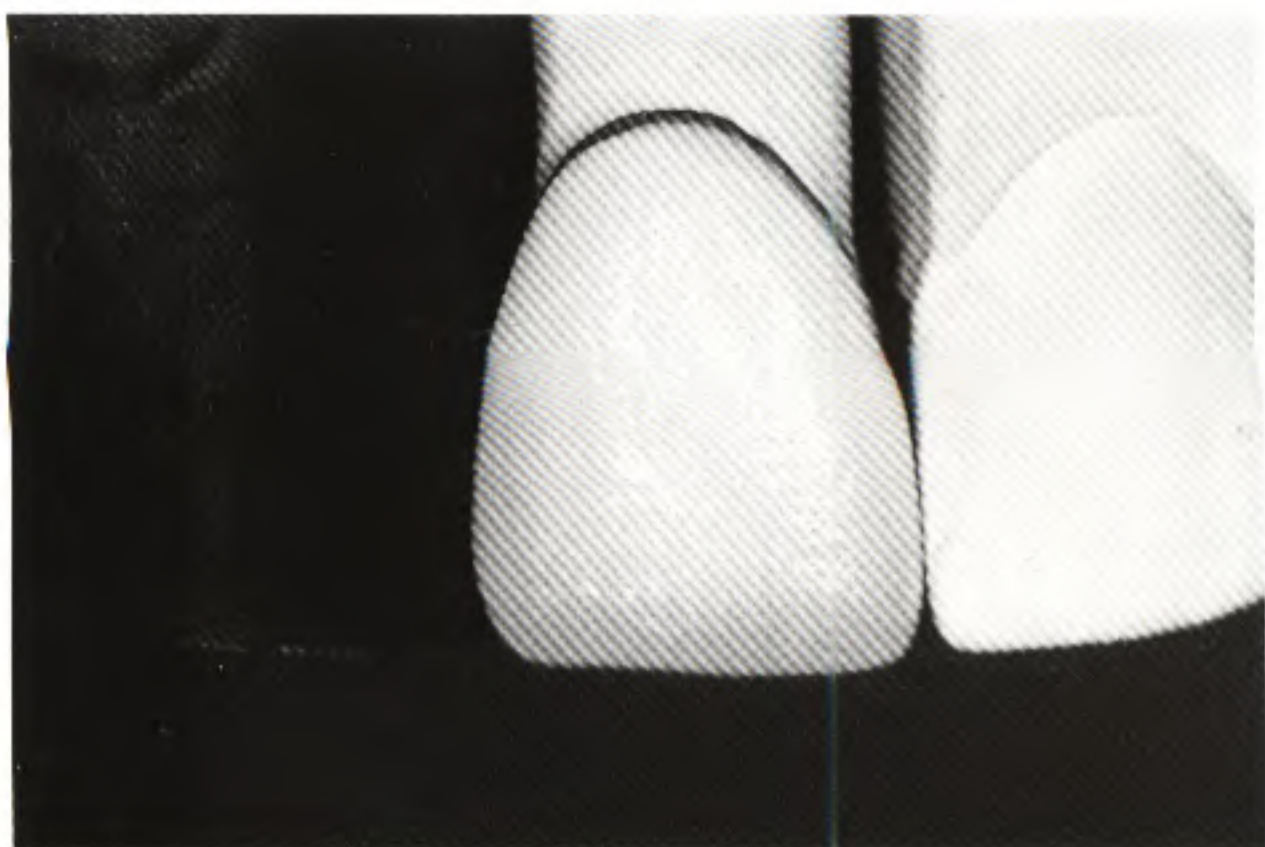


Fig 9-18 Check one interproximal area with the opposite stone teeth removed. After the mesial contact has been adjusted, check and adjust the distal interproximal contacts as needed.



Fig 9-19 As you approach the final stages of adjusting and contouring, periodically moisten the dental porcelain with distilled water. This simple step will aid your evaluation of the restoration's shape, color (shade), and the level of translucency. During contouring, the dry porcelain takes on a chalky appearance and the true shade and translucency cannot be visualized and fully appreciated unless the surface is wet.

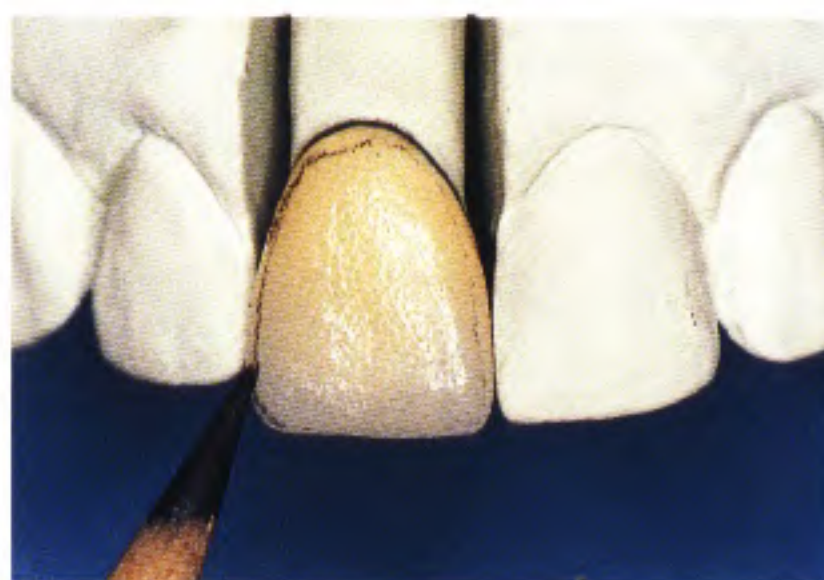


Fig 9-20 You may find it helpful to outline the final form you wish to create for the restoration. Use a pencil to mark the extent of the axial line angles on the facial surface and identify the marginal ridges on the lingual surface.



Fig 9-21 Use a Busch Silent Stone to bring the facial surface to the desired final contour. Adjust the incisal edge to the proper length and shape.

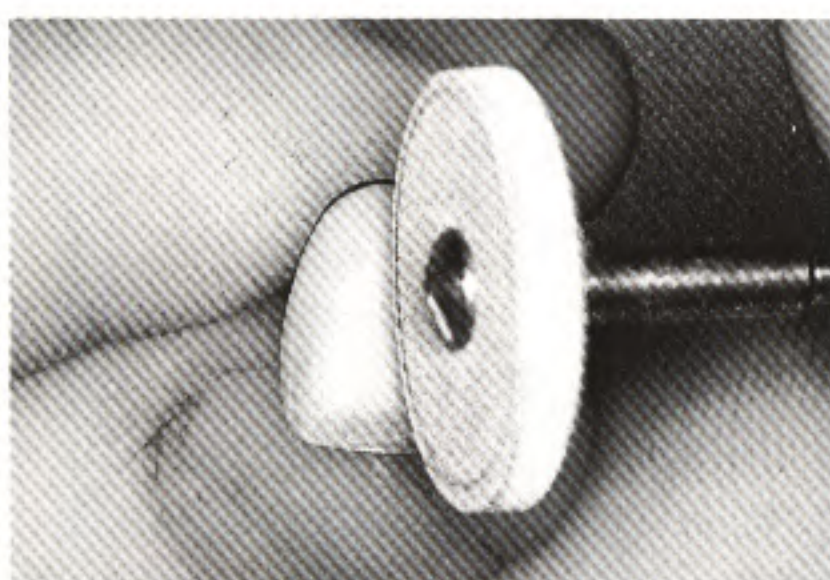


Fig 9-22 Use a porcelain prepolishing wheel to smooth the facial surface (Vident Pre-Polish Wheel shown).



Fig 9-23 After air-abrading and steam cleaning the restoration, return it to the master cast to check the contact areas with shimstock. Make any required refinements using the same procedures described earlier. If you have a solid (uncut) cast, seat the restoration on that cast to evaluate your adjustments.

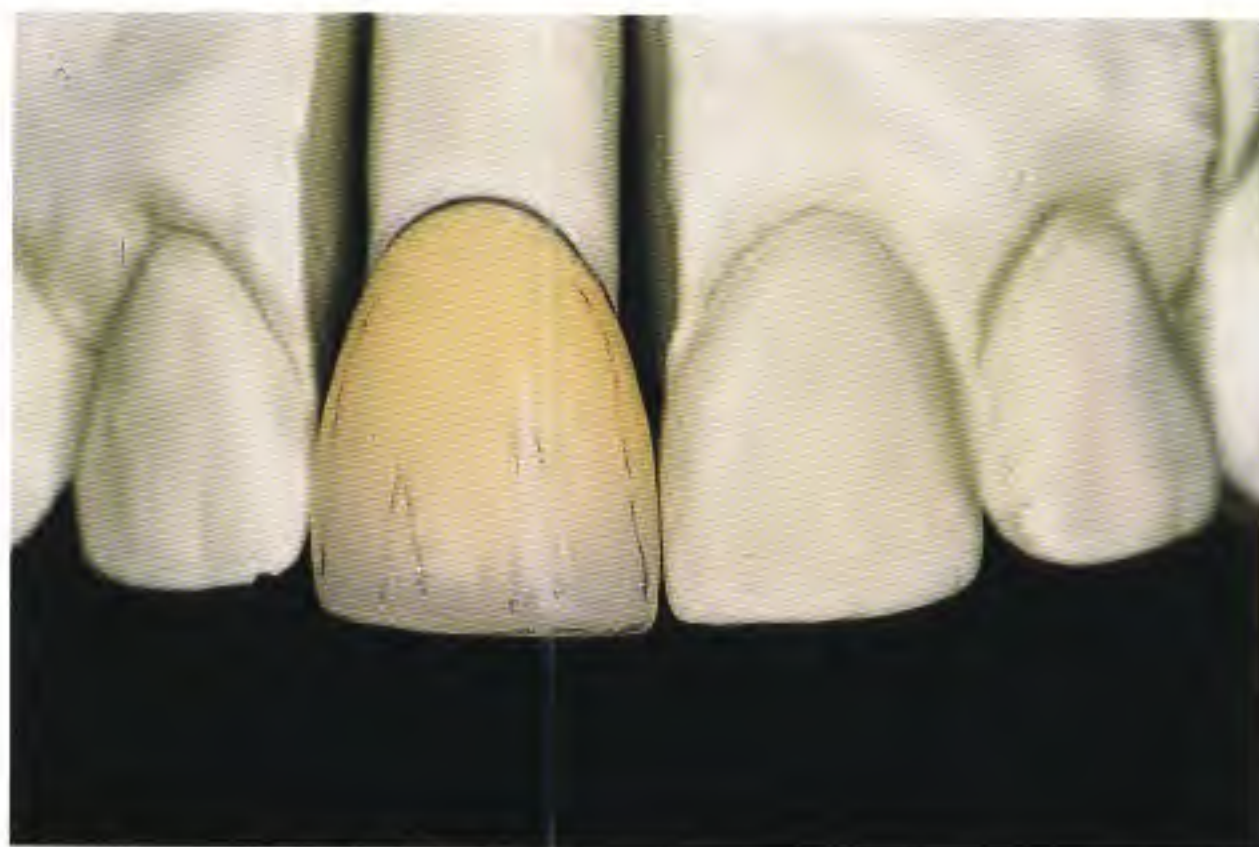


Fig 9-24 Mark the location of desired characterizations directly on the facial surface with a pencil or other marking device. Select an abrasive with the appropriate shape and grit to create the desired effect.



Fig 9-25 Avoid creating effects that appear abrupt and unnatural, because the crown is apt to look more like a denture tooth than a natural tooth.

shaping and end with a fine polishing material (eg, Vident Porcelain Pre-Polish Wheel) to establish a smooth surface finish. Follow the steps illustrated in Figs 9-19 to 9-23.

Once the axial and interproximal contouring have been completed, adjust the occlusion according to the requested occlusal scheme. There are different philosophies of occlusion, each with its own unique demands, so check the laboratory work authorization or call the requesting doctor for guidance on this subject.

Establishing surface texture (Figs 9-24 and 9-25)

After the occlusion and contours have been perfected, attention can be devoted to re-creating facial anatomy and surface texture of the adjacent natural teeth. The choice of instruments and technique will often depend on the shape and surface character desired. The instruments used in this final phase may vary from coarse abrasives for very textured teeth to diamond prepolishers for teeth with a highly polished and glassy finish.

Once the desired texture has been created, go over the porcelain surface with a prepolishing wheel, flexible, fine diamond disk, or sandpaper disk to smooth and blend any areas that appear too rough.

Finishing the porcelain-metal junction

The next step is to finish the porcelain-metal junction. This area has the potential to become a region with

increased surface roughness. If this interface is not carefully finished and smoothed, it can act as an irritant when in contact with the patient's gingival tissues. Furthermore, overadjustment of the porcelain-metal junction can expose the rough layer of opaque porcelain. Once exposed, the opaque layer cannot be glazed or polished to the same level of smoothness as the body porcelain. What results is a region on the occluding surface that can cause excessive wear of the opposing natural dentition (enamel or dentin) or restorative materials (eg, glazed porcelain, Type III or IV gold, dental amalgam, or composite resin).

Examine the restoration for any obvious overextensions of porcelain at the porcelain-metal junction (Fig 9-26). If there are overextensions, remove them with a fine stone, diamond abrasive, or a prepolishing wheel. Do not use a Busch Silent Stone to refinish a slight overextension; instead, select a fine ceramic stone or use a porcelain prepolymer if the overextension is accessible to this size wheel. Otherwise, you will have to repeat the finishing procedure with a series of sequential finishing points or stones of finer grit. Assuming any overextensions have been removed, use a diamond prepolishing wheel to polish the porcelain and the metal of the porcelain-metal junction at the same time (Fig 9-27).

If this junction is not finished prior to glazing, the porcelain will almost certainly be adjusted during the final polishing. Grinding after the glaze firing will expose unglazed porcelain in this area. Unless careful porcelain polishing procedures are performed, this region will not be as smooth as the glazed porcelain itself. In addition, metal polishing compounds can become embedded in these unglazed areas. Since particles of residual polishing agents are extremely



Fig 9-26 Examine the restoration for overextension of porcelain at the porcelain-metal junction. Use a fine stone, fine diamond abrasive, or a prepolishing wheel to remove the porcelain without damaging the metal substructure.

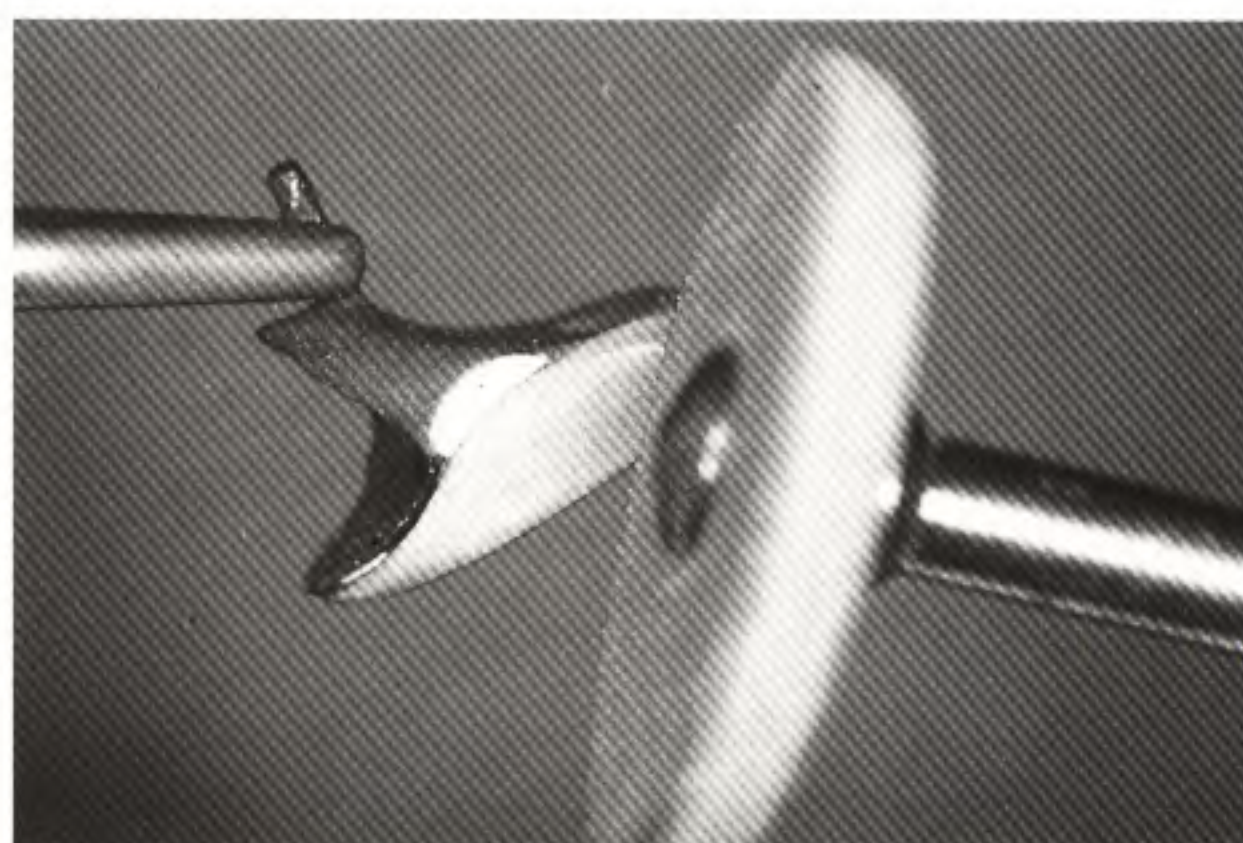


Fig 9-27 After removing a porcelain overextension, smooth the adjusted area with a prepolishing wheel because it will polish both the porcelain veneer and the metal substructure.

Fig 9-28 A fine-grit emery disk removes porcelain from the metal collar while smoothing both the metal and the adjacent porcelain.



difficult to remove, they can subsequently discolor the fired porcelain.

Finishing the labial margin

Finishing at the labial margin is a delicate and tedious procedure. Any marginal finishing done on the master die can abrade the gypsum and result in a crown that fits the abraded die, but these margins may be short on the prepared tooth. It is safer to finish margins with the restoration on a second die, if available. In the case of a crown with a porcelain labial margin, it is recommended that marginal contouring be done with a diamond prepolishing wheel, preferably under a stereomicroscope (Yamamoto, 1990).

When great care is taken, it is possible to perform some of the marginal finishing procedures with the restoration held securely in your fingers. Generally, a

$\frac{5}{8}$ -in. fine-grit emery disk works well in removing porcelain from the labial metal collar (Fig 9-28). Use extreme caution in maintaining a proper emergence profile angle, and at the same time be careful not to damage the metal margins.

Completing the contouring

An additional measure for checking the axial and occlusal contour is to place the restoration on a cast that does not have removable dies. This will generally give an indication of how well the restoration will fit in the mouth. Many times you will find that the interproximal contacts may still be too tight and need further adjustment. This procedure will greatly decrease the dentist's chairside time required for crown insertion.

At this point, the contouring, occlusal adjustment, and finishing at the porcelain-metal junction have

Table 9-1 Guide to color modifications

Desired change	Procedure	How to do it	Secondary effects
Change the hue	When the dominant hue is yellow, shift to a red/yellow (orange) hue	Add red	None
Change the hue	When the dominant hue is red/yellow (orange), shift to a yellow hue	Add yellow	None
Make a color <i>more</i> intense	Increase the chroma	Add the dominant hue	None
Make a color <i>less</i> intense	Decrease the chroma	Add the complementary color of the dominant hue	Decreases the value
Make the shade <i>lighter</i>	Increase the value	Add a stain of a higher value	Not recommended (better to remove the porcelain)
Make the shade <i>darker</i> (more gray)	Decrease the value	Add the complementary color of the dominant hue	Decreases the chroma

been finalized. The surface texture has been perfected to harmonize with the adjacent teeth. The restoration is now ready for characterizing (staining), glazing, and polishing of the metal substrate.

Fundamentals of color science

Until you have mastered the techniques of internal color development, you will probably find that a metal ceramic crown or fixed partial denture can be improved by surface characterization (staining). In fact, there are instances where certain shade and stain modifications can make a dramatic difference in the esthetics of the final restoration. Likewise, there will be situations where attempts at some types of color correction would prove futile in correcting certain color discrepancies. Knowing the difference between the two situations comes with experience and from an understanding of color science and color correction techniques.

Very often, minor color adjustments can be made using only small additions of surface stains (Table 9-1). Too much surface staining, on the other hand, may reduce translucency by literally blocking light that would otherwise pass through areas of the porcelain. Inappropriate attempts at color correction can make a bad situation worse.

Before undertaking any discussion of porcelain characterization or color correction, you must have some appreciation of the fundamentals of color science. Once you have some understanding of color,

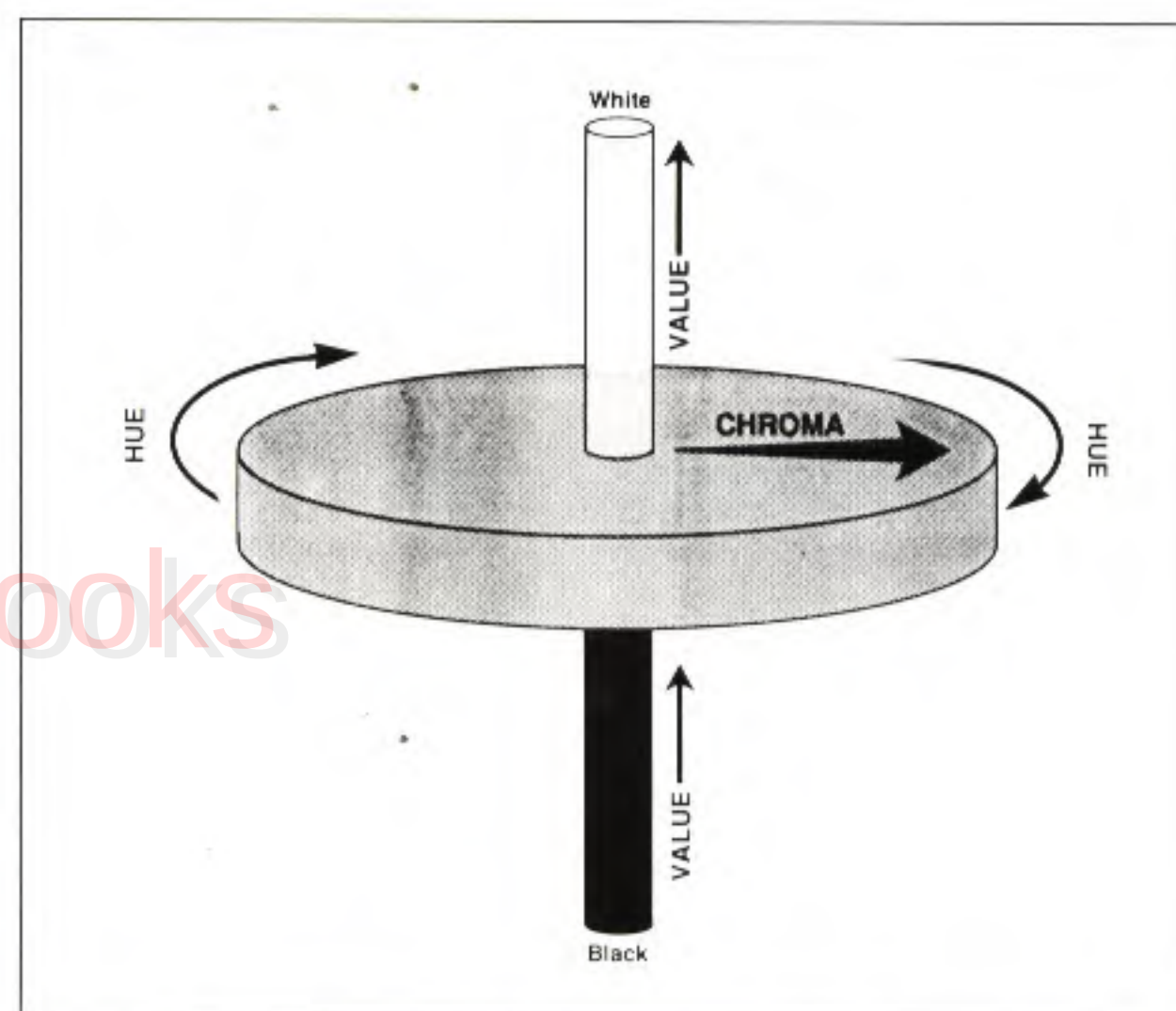


Fig 9-29 On the color wheel, hue makes up the wheel's rim, value serves as the hub, and chroma forms the spokes.

the dimensions of color, and the color systems, you will have a better appreciation of the capabilities and limitations of color mixing. The following is a very basic discussion on the subject of color. For additional information on color and esthetics, consult some of the more advanced texts (Hegenbarth, 1989; Korson, 1990; McLean 1979, 1980; Muia, 1982; Mütterthies, 1990; Preston and Bergen, 1980; Rinn, 1990; Yamamoto, 1985, 1990).

The three dimensions of color

What we refer to simply as *color* is actually a complex science that was described by Munsell in the Munsell Color Ordered System as having three dimensions: hue, value, and chroma (Munsell, 1936; Preston and Bergen, 1980). Together, these three dimensions form a color solid that is an irregular sphere in shape. If you were to examine a cross section of that sphere you would find that it has the appearance of a wheel. Thus, it is common to find discussions on color science in which the three dimensions of color (hue, value, and chroma) are depicted as a wheel (Fig 9-29).

Hue

Hue is the dimension of color that enables you to distinguish one family of color from another. For example, green and red represent two different color families, so they are different hues. In the Munsell Color System, the various hues make up the rim of the color wheel (see Fig 9-29).

Value

Value is the dimension of color that permits you to describe relative differences in whiteness or blackness. A restoration with a low value would be very dark, whereas a crown with a high value would appear bright by comparison. In other words, value can be used to describe a restoration in terms of its brightness, lightness, or brilliance. Value is independent of hue (Preston and Bergen, 1980). On the color wheel, value is the hub of the wheel (Sproull, 1973; see Fig 9-29).

By some accounts, value is the most important of the three dimension of color (Dykema et al, 1986). The human eye cannot perceive subtle differences in hue or chroma, but variations in value are more easily detected.

Chroma

The third dimension of color is chroma, which refers to what has been described as the relative concentration or strength (Preston and Bergen, 1980), saturation (Preston, 1983), or intensity of a hue (Dykema et al, 1986). The more intense a color is, the higher its chroma level. When comparing a navy blue object to one that is powder (light) blue, the darker navy blue object has a higher blue chroma. On the color wheel (see Fig 9-29), chroma makes up the spokes of the wheel.

Color systems

Light-mixture (or additive) color mixing system

When white light is passed through a glass prism, the prism separates the individual colors of the visible light spectrum (ie, violet, blue, green, yellow, orange, and red). If you were to look very closely you would note three large bands of color: blue, green, and red. These are the three primary colors, and because they are part of the visible light spectrum, they may be more correctly defined as the three light-mixture (or additive) primary colors (Fig 9-30, A). Combining any two of the primary colors in the light-mixture system will produce a secondary color. For example, mixing red and green light will produce the secondary color of yellow. Combining green and blue will yield cyan. Blue and red create magenta. These are all light-mixture (or additive) secondary colors (Fig 9-30, B). When the primary and secondary colors are combined, they form a color wheel (Fig 9-30, C).

It is important to note that the light-mixture (or additive) color system only describes the color mixing of lights or illuminants and does not apply to the mixing of pigment systems (Dykema et al, 1986; Preston and Bergen, 1980). The mixing of paints or pigment is described using the pigment-mixture (or subtractive) color mixing system.

The pigment-mixture (or subtractive) color mixing system

The subtractive color system is used for pigmented objects and is helpful in explaining the effects obtained with extrinsic staining. Understanding the pigment-mixture (or subtractive) color mixing system is easy because it is simply the opposite of the light-mixture (or additive) color mixing system. In other words, the three primary colors of the subtractive color system are the secondary colors from the additive system, namely: yellow, cyan, and magenta (Fig 9-31, A). The secondary colors of the pigment-mixture (or subtractive) color mixing system are the primary colors of the light-mixture (or additive) system, namely: red, green, and blue (Fig 9-31, B). The primary and secondary colors of the subtractive color mixing system also combine to form a color wheel (Fig 9-31, C).

The pure subtractive color system is applicable if the pigments that are added permit light to pass through them (Preston and Bergen, 1980). Because dental porcelain colorants are opaque to some degree and can actually block light transmission, some

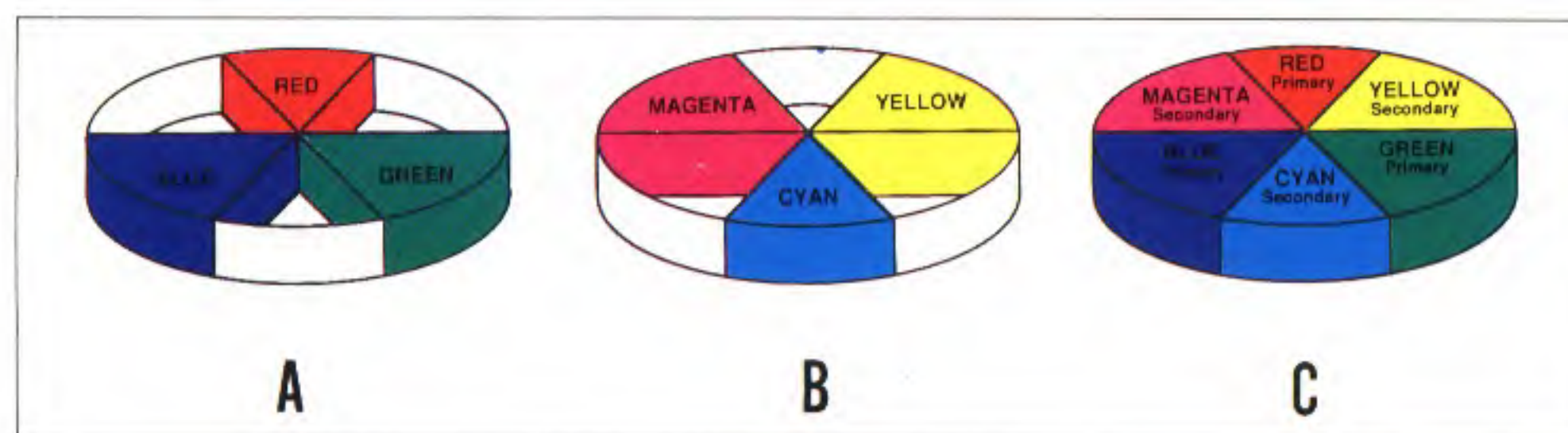


Fig 9-30 The color wheel of the light-mixture (or additive) color mixing system with its three primary colors (A), its secondary colors (B), and its combined color wheel (C).

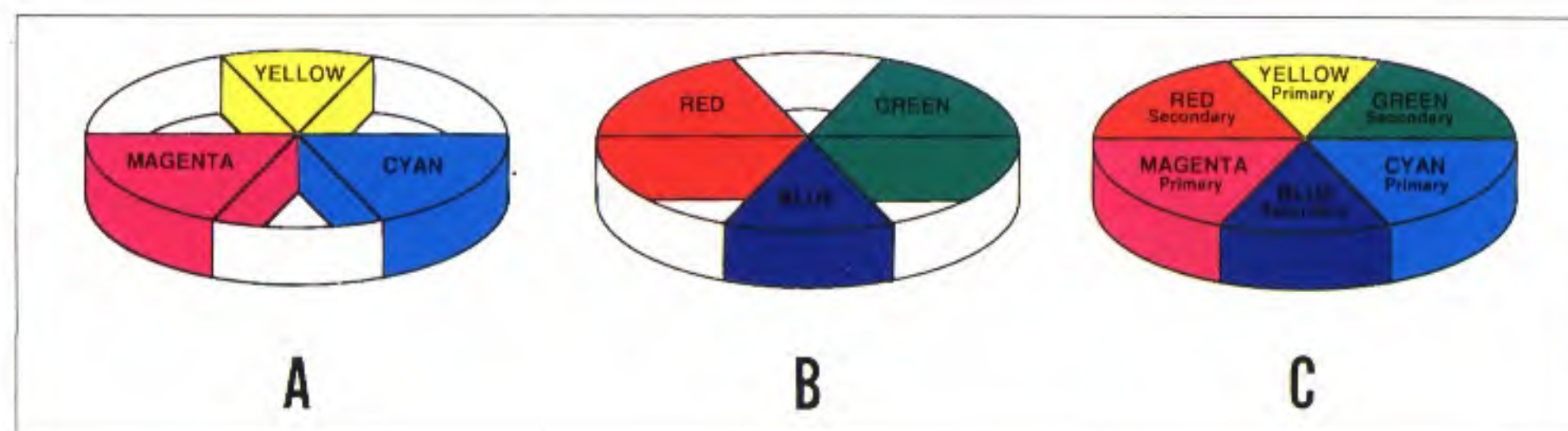


Fig 9-31 The color wheel of the pigment-mixture (or secondary) color mixing system with its three primary colors (A), its secondary colors (B), and its combined color wheel (C).

color experts adhere to a third concept of color mixing, referred to as the partitive color system (Preston and Bergen, 1980). Owing to the complexity of the theory behind this third color system, interested readers are advised to refer to references cited at the close of this text for more information.

Complementary colors

Colors directly opposite one another on either color wheel are referred to as complementary colors. To locate a complementary color, draw an imaginary line from one color through the center of a color wheel and it will pass through its complementary color. Therefore, in the light-mixture (or additive) color mixing system, the primary color red is the complement of the secondary color cyan, green is the complement of magenta, and blue is the complement of yellow (see Fig 9-30, C). Mixing any two complementary colors in the additive color system produces white light.

With the pigment-mixture (or subtractive) color system, colors opposite one another on the color wheel are also called complementary colors, but when mixed together they produce black. The three possible combinations of complementary colors in the subtractive color system include yellow and blue, cyan and red, and magenta and green (see Fig 9-31, C).

Color correction of dental porcelain

One of the first steps in color correction is to determine if the hue, chroma, or value of the restoration needs to be modified in any way. Table 9-1 contains guidance on different types of modifications. If only minor shade alternations or characterizations of the porcelain are necessary, such adjustments generally can be accomplished by firing stains on the external surface of the restoration. This "characterization" can be performed before or in conjunction with a glazing procedure.

Staining and glazing the porcelain

After a restoration has been adjusted and finished, it is often necessary to make minor color corrections or additions and create a lifelike surface luster. These color modifications are made with the aid of surface stains. Although the process is often referred to as "staining," some clinicians prefer to describe the procedure as a characterization of the final restoration when describing it to patients. Because patients have the perception that their metal ceramic restoration will re-create an unrestored tooth, to them the word staining may take on a negative rather than a positive connotation.

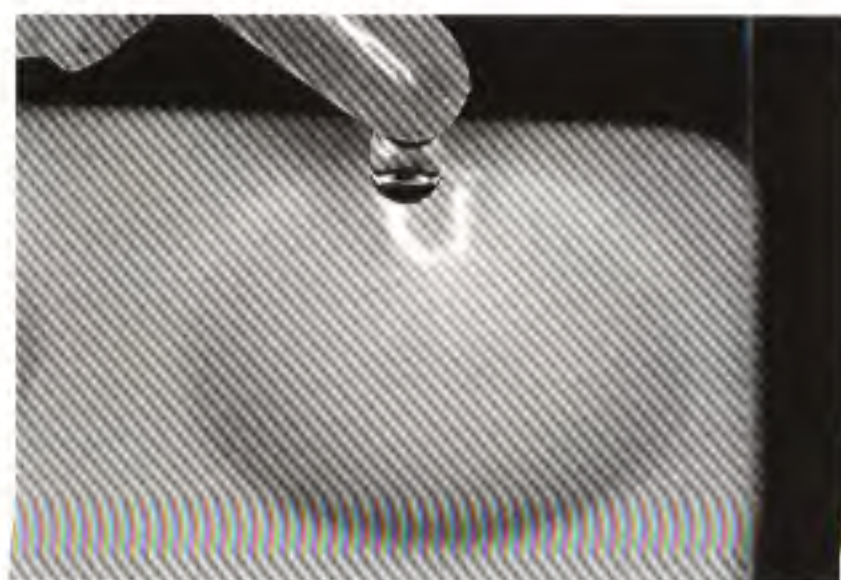


Fig 9-32 To mix the stain powder with the liquid medium properly, place one or two drops of the liquid in a reservoir in a stain tray.



Fig 9-33 Dispense stain powder with either a metal spatula or glass mixing rod. Next, slowly add the stain powder to the liquid and thoroughly mix the two together with a small glass or plastic mixing instrument. Do not use a brush when mixing stains (or porcelains for that matter) because the bristles contain air that can introduce bubbles into the mix.

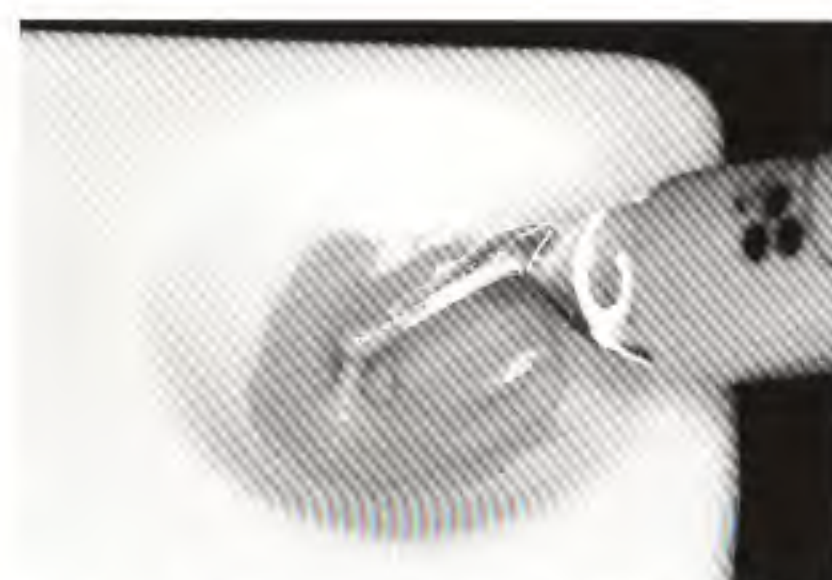


Fig 9-34 Use the glass rod to test the stain mixture to make certain it has been mixed to a thick, creamy consistency.

The natural luster or sheen that must be developed for the restoration is achieved through one of two glazing procedures and augmented with a mechanical polish. The two types of glaze (and the glazing methods) are a natural glaze and an overglaze (DeVreugd and Eissmann, 1980; Glossary of Prosthodontic Terms, 1987). Dental literature published before this revision in terminology contains the older term self-glaze (McLean, 1979, 1980; Yamamoto, 1985) instead of natural glaze as well as the term applied glaze (Kuwata, 1980) instead of overglaze. You should become familiar with all these terms so you understand which of the two techniques is being discussed.

Although the methods of achieving a surface glaze may differ, the stains used for both glazing techniques are the same. Consequently, the combined procedures of characterizing (staining) and glazing will be discussed jointly, because they are so intimately linked.

Materials

Color modifications can be readily accomplished with the application and firing of porcelain surface stains. These stains consist of metallic oxides of varying hues carried in a vehicle of low-fusing dental porcelain. The oxide pigments incorporated in the various stains are color stable at high temperatures. Consequently, what you see in the unfired state generally is comparable to, but not always exactly like, the appearance of the stains after they have been fired.

Manufacturers and distributors of dental porcelain

systems typically market the porcelain stain kit as a separate item. Fortunately, it is not always necessary to use a specific brand with its companion body porcelains. Because stains are applied in such small amounts, they can generally be interchanged between brands of metal ceramic porcelain. Yet, whenever practical, it is wise to use a system (ie, body porcelains and stains) from the same manufacturer.

The porcelain stains in a typical kit are most often supplied as a powder and accompanied by a bottle containing a slightly viscous fluid or stain medium.

Mixing stains (Figs 9-32 to 9-34)

Invariably, the stain liquid is nothing more than a mixture of glycerin and water. This special liquid has the advantage of being slow to evaporate. This means the mixed stains do not dry out readily and can be stored long term. However, mixed stains are best stored in a special tray with an air-tight lid or at least a cover to protect the stains from contamination by dust or other debris.

If the mixed stains are too diluted, they tend to run when applied and also to lose their intensity when fired. As a general rule, stains are mixed thick but applied thin. The stain medium also allows for even distribution of the stains once it has been applied to the prepared porcelain surface. If you have a large ceramic tray, prepare a palette of many different colors so you have the ability to mix, blend, and dilute a variety of stains. Although it is rare, a few manufacturers do offer premixed stains that do not require mixing or wetting before use.

Staining technique (Figs 9-35 to 9-42)

Regardless of whether you use conventional stain powders or premixed stains, the procedure for applying and firing those stains is the same. The first step in the staining procedure is to wet the porcelain surface with the clear stain medium. This liquid should be

applied in a thin, uniform layer. Moistening the surface in this way will help you to visualize what the crown will look like once it is glazed. In addition, this procedure makes the stains easier to apply. Be careful to avoid applying too much stain medium which could subsequently cause the stains to run and pool.



Fig 9-35 Surface stains should be applied with a small sable brush (Tanaka Dental). In many instances, certain characterizations require a very controlled application technique.

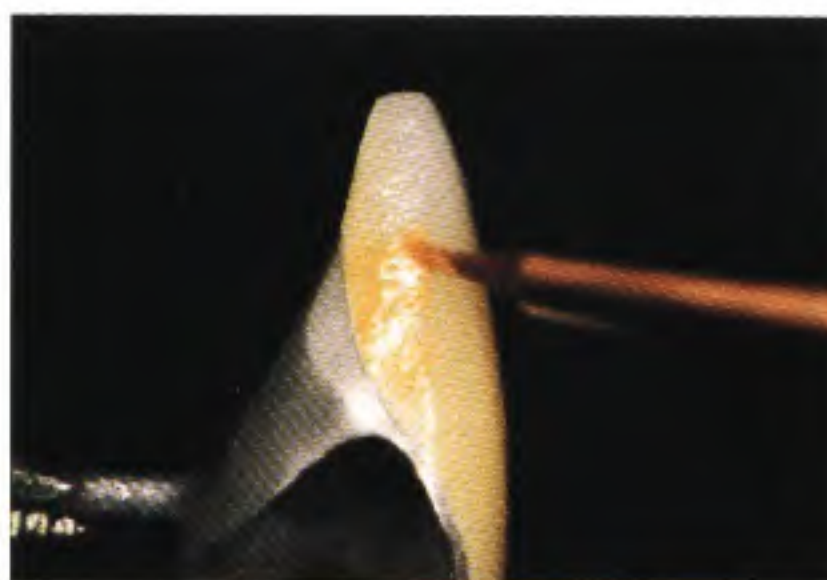


Fig 9-36 Place the stain in the area where the characterization is intended. Blend or dilute the effect of the stain as desired.



Fig 9-37 When stains are to be placed over a small area of the restoration, a small brush (*left*) is adequate, but if you want to apply an overglaze on the ceramic surface a large stain brush (*right*) may make the process easier.



Fig 9-38 An overglaze is prepared similarly to stains in that a drop of liquid is placed in the ceramic dish and the glaze powder is added to the liquid. The glass rod is used to wet the powder.



Fig 9-39 The glaze is picked up with a staining brush and applied to the ceramic surface where desired.

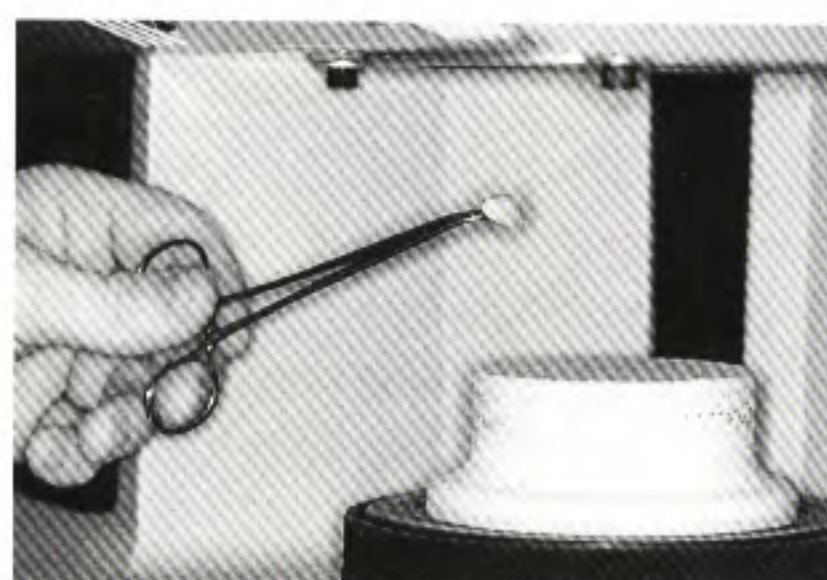


Fig 9-40 Carefully and slowly dry the restoration in the porcelain furnace muffle entrance.



Fig 9-41 Any clear glaze or stain that was inadvertently placed on the metal surface will appear as a dry, white powder that can be easily removed with the small stain brush.

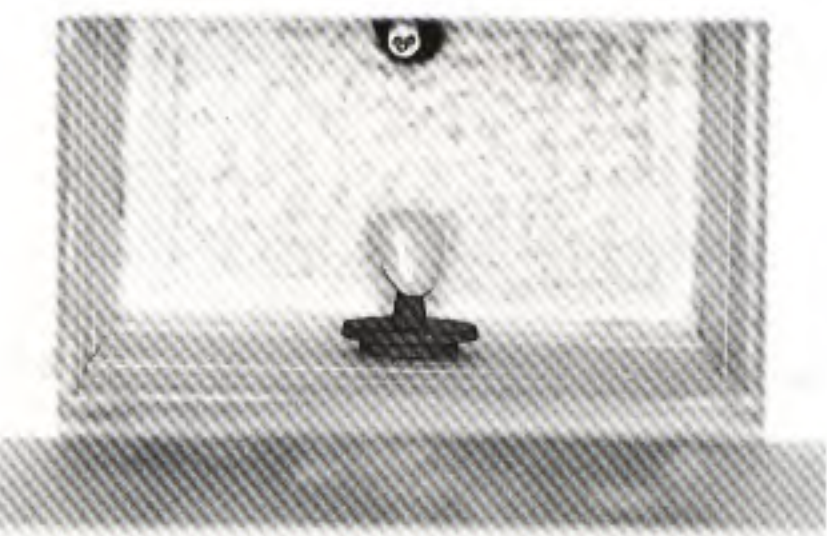


Fig 9-42 After you have removed excess porcelain from any unwanted areas and inspected the inside of the casting for evidence of debris, place the restoration in the porcelain furnace and fire it according to the porcelain manufacturer's directions.

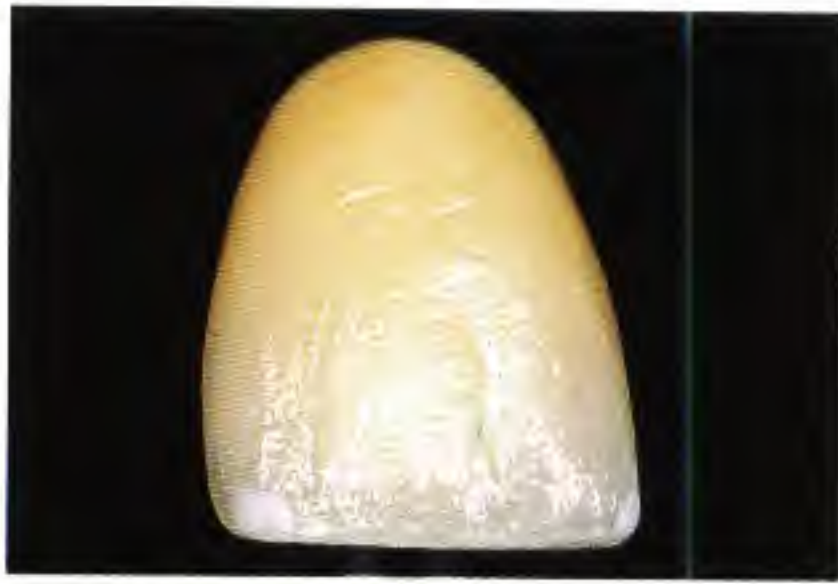


Fig 9-43 An underfired restoration will undoubtedly retain much of its pebbly ("orange peel") appearance with very little evidence of surface changes.



Fig 9-44 The overfired crown will possess an extremely reflective, glossy surface devoid of surface characterization and show signs of rounding of previously sharp corners.



Fig 9-45 There is no "correct" level of glaze, because the amount of characterization actually depends on the features that must be reproduced to harmonize with an individual patient. However, this shows a more typical glaze, which lies somewhere between underglazing and overglazing.

Natural glazing (Figs 9-43 to 9-45)

A natural glaze (or self-glaze) simply refers to the process in which the restoration is fired to a temperature that is usually equal to or slightly higher than the original firing temperature. If the crown is to have a natural glaze, it will be fired after the stains are applied according to the porcelain manufacturer's instructions for the natural glaze technique (see Appendix B). The restoration should first be allowed to dry at the entrance of the furnace muffle until the stain medium has evaporated completely, leaving a dry, chalky surface. Then the crown is slowly inserted into the furnace and fired to the manufacturer's recommended natural glazing temperature. Once at temperature, the crown is either removed immediately from the porcelain furnace or held at the recommended glazing temperature for a short period of time, usually 1 to 2 minutes, until the outer surface of the porcelain develops the desired level of gloss. The porcelain surface of the restoration is exposed to temperatures high enough to permit the porcelain to fuse together and create a smooth, glossy outer "skin." This procedure is accomplished with no vacuum (ie, at atmospheric pressure). During this firing cycle the surface of the porcelain vitrifies (melts) and fuses just enough to fill in slight surface irregularities or porosities. The result is a smooth, glazed surface. Since self-glazing porcelain is based on a time-temperature relationship, the higher the temperature, or the longer the work is held at that temperature, the smoother the surface will become. The actual glazing temperature selected and the length of the hold time will vary from one brand of porcelain to another, depending on the maturation temperature and fluidity of the given dental porcelain (see Appendix B).

If the porcelain is inadvertently raised to too high a temperature or held at the natural glazing temperature for too long a period, the porcelain can slump (undergo pyroplastic flow), the restoration can lose natural contours, recrystallize, and become opaque (devitrify). These changes are particularly noticeable when sharp areas of porcelain, such as the mesial and distal corners of incisor teeth, lose their original shape and become rounded. You may even notice regions of the porcelain that develop a chalky white color. These observations are more a reflection of problems with porcelains that are highly fluxed (ie, are formulated to be more fluid at high temperatures). In an effort to control surface texture and avoid any loss of contour, the ceramist must be familiar with the manner in which each porcelain glazes at a given temperature in a specific porcelain furnace. For most porcelains, the ideal firing temperature will result in the desired glaze within 2 minutes. Larger work, such as long-span fixed partial dentures, may need to be held at temperature for longer periods of time than single-unit restorations.

When attempting to determine the ideal hold time, remember that it is preferable to underglaze rather than overglaze the porcelain initially. If after your first attempt at glazing you regard the natural glaze as less than adequate, simply refire the restoration to a slightly higher maximum temperature or extend the hold time. However, if the glaze is excessive after the first attempt, it may require that the entire surface be recontoured and reglazed.

Overglaze technique

When a restoration has been heavily characterized

with external stains or you've selected a porcelain labial margin finish line for your case, you may not want to subject it to the high temperatures required for a natural glaze. Fearing damage either to the stains or to a porcelain labial margin, you may opt for an overglaze (applied glaze) for the ceramic veneer. This overglaze is nothing more than a thin layer of clear porcelain that can artificially create a high sheen on the restoration. An overglaze is a low-fusing porcelain that is fired at a temperature that is generally 20° to 60°C lower than the firing temperature of the body porcelains.

If you choose to apply surface stain and use an applied glaze, the technique generally can be carried out in one of two ways. With the first technique the stains are fired to their fusing temperature, the results are evaluated after the crown cools, then an applied glaze is placed over the stains and the restoration is fired once again. Although this technique is more time-consuming than the previous one because it requires a second glaze firing, it does have its advantages. In fact, this technique has been recommended by some authors because it has been shown to slow the loss of surface stains from the surface, which would then result in a change in the shade of the final restoration.

The second technique requires that the porcelain first be moistened with a clear overglaze rather than the glaze medium used in the first technique. The stains are then applied directly to the porcelain surface previously wetted with the clear glaze. This initial layer of clear glaze fills the surface pores and creates a uniformly moistened surface to accept any stains. The restoration, with clear glaze and stains applied, is slowly dried in the muffle entrance as before and fired to the recommended glazing temperature for an applied glaze (see Appendix B).

As with natural glazing, these glazes are also air-fired. Care must be taken when using such materials to prevent pooling or filling in of the surface texture that has purposely been adjusted to mimic the texture of the adjacent natural teeth. In addition, some applied glazes will discolor in areas where they are allowed to pool. When an acceptable glaze is finally

achieved, the restoration should require only metal polishing before delivery to the patient. If the finishing procedures for the porcelain-metal junction have been properly accomplished, as described earlier in this chapter, the final metal polishing procedure is a very simple one.

In all likelihood, a novice ceramist can achieve excellent esthetics and probably make satisfactory shade changes or color modifications when using surface stains in conjunction with an applied glaze.

Evaluating the glaze and surface texture

After the restoration has completed the glazing cycle, carefully evaluate it to determine if it has the proper level of glaze and the correct amount of surface texture. The appearance of a glazed ceramic surface will not only depend on the time and temperature to which the crown was fired, it will reflect the extent of surface roughness or smoothness in the ceramic surface (see Figs 9-43 to 9-45).

Mechanical polish (Figs 9-46 to 9-51)

Despite the outward appearance of an acceptable level of glaze, a more natural, lifelike restoration is obtained by mechanically polishing the ceramic surface after the glazing procedure. It makes no difference if the crown was given a natural glaze or an overglaze; mechanical polishing will probably improve its appearance. At the very least, mechanical polishing removes minor surface irregularities that are produced by an overglaze and improves surface smoothness. More importantly, mechanical polishing can help transform the glassy appearance of a glazed ceramic surface to a more natural luster of human enamel.

With the pumice and Brasso technique of mechanical polishing, it is extremely important to apply the polishing paste liberally over the ceramic surface. With both this material and the Insta-Glaze, care should be taken, because mechanical polishing can remove some surface stains.



Fig 9-46 A number of manufacturers sell a diamond polishing paste (eg, Insta-Glaze, George Taub). The paste is dispensed on a pad and applied with a polishing point or wheel.



Fig 9-47 The crown is held securely in one hand and intermittent pressure is applied using a liberal application of polishing paste and a polishing wheel. Depending on the amount of pressure used and the length of the polishing procedure, the diamond paste can smooth the ceramic veneer quite well.

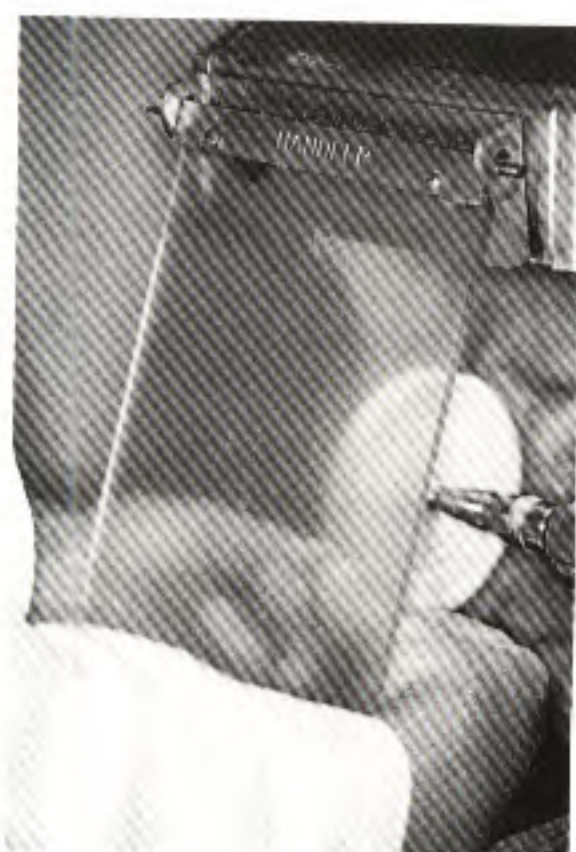


Fig 9-48 (left) An inexpensive alternative to commercial diamond pastes is a mixture of Brasso (Airwick Industries) and flour of pumice (Moyco). When combined, the two ingredients make a thick, creamy, and inexpensive polishing paste that can be prepared and stored in a resealable jar. A unit dose of the prepared paste can be placed in a dappen dish with a metal spatula for each case, to avoid cross contamination of the large jar.

Fig 9-49 (right) A tight, wet rag wheel at high speed on a bench lathe is best suited for mechanical polishing, especially if the wheel is firm and offers resistance during polishing. Make sure the safety shield is in the correct position before operation is begun to avoid throwing liquid or paste in the operator's face. Apply a liberal amount of pumice and Brasso mixture to the ceramic surface.



Fig 9-50 Press the crown against the rotating wheel, being sure to protect the crown margins at all times. Rotate the crown periodically to polish in all directions. Be sure to reapply more paste and water to prevent overheating of the porcelain.



Fig 9-51 Facial view of the crown in Fig 9-45 after mechanical polishing with pumice and Brasso. Note the reduction in the glassy sheen and the natural rounding of the facial grooves. A lifelike luster is created in the ceramic yet the surface characterization (white opacification) remains. Compare these results with Fig 9-45 to see the effects of mechanical polishing.

Polishing the metal substructure

Polishing of the metal substructure can be completed in three relatively easy steps: initial finishing, preliminary polishing, and a final polish.

Initial finishing (Figs 9-52 to 9-56)



Fig 9-52 (left) First, cut off the metal handle using a thin carborundum disk.



Fig 9-53 Recontour this area with a stone. Finish the cingulum area with an appropriate abrasive until the area is smooth and the proper contour is restored.



Fig 9-54 (left) Use a green rubber polishing point to smooth the remainder of the lingual surface.



Fig 9-55 Use a porcelain prepolishing wheel to remove any obvious scratches, irregularities, and oxidation from the metal's surface that appeared subsequent to your initial metal finishing. This wheel will not remove the glaze, so the metal is smoothed to the porcelain-metal junction without marring the glazed ceramic veneer. If a more abrasive wheel were used, the glazed surface could be broken.



Fig 9-56 At this point all metal surfaces should have a high sheen and the glazed porcelain should remain unmarred. This is why finishing the junction of porcelain to metal prior to glazing is such a critical step (see chapter 7).

Preliminary polishing (Figs 9-57 to 9-59)

Fig 9-57 Preliminary polishing is intended to transform the smooth metal surface left behind by the rubber wheels and points to a more highly polished state. Polishing agents, such as Bar Body Compound (BBC, J.F. Jelenko & Co), tripoli (William Dixon), and rouge (Buffalo Dental Manufacturing Co), can be used.

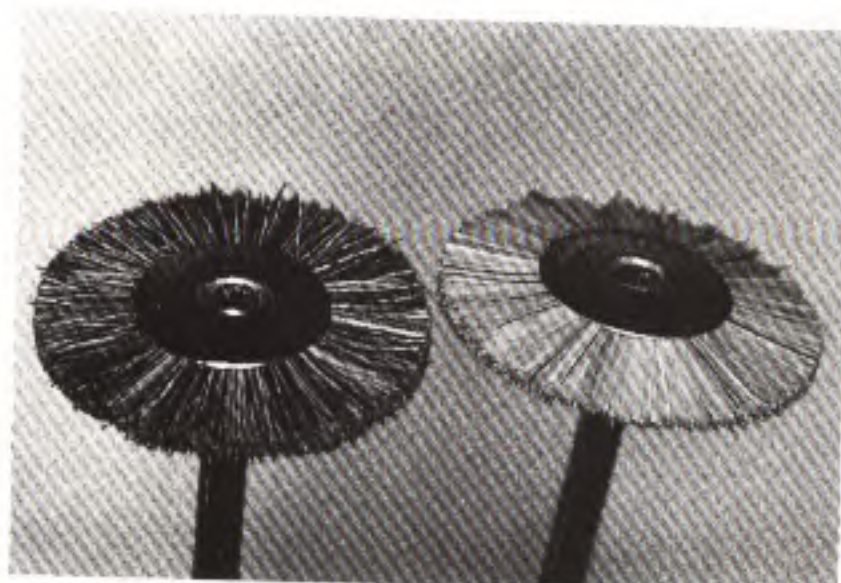


Fig 9-58 Several types of brushes are available for transporting the polishing agents: soft bristles (left) and hard bristles (right) (Robinson brushes, Buffalo Dental).



Fig 9-59 Slowly rotate the brush in the BBC abrasive, and the brush will pick up the polishing compound. Using light pressure and great care, slowly rotate the brush loaded with BBC over the metal surface. As the procedure is mentioned previously, try to avoid bringing the polishing compounds in contact with the glazed porcelain. After the metal surface has been polished with BBC, remove all the residual polishing compound with a steam cleaner or ultrasonic cleaner before moving on to a high shine.

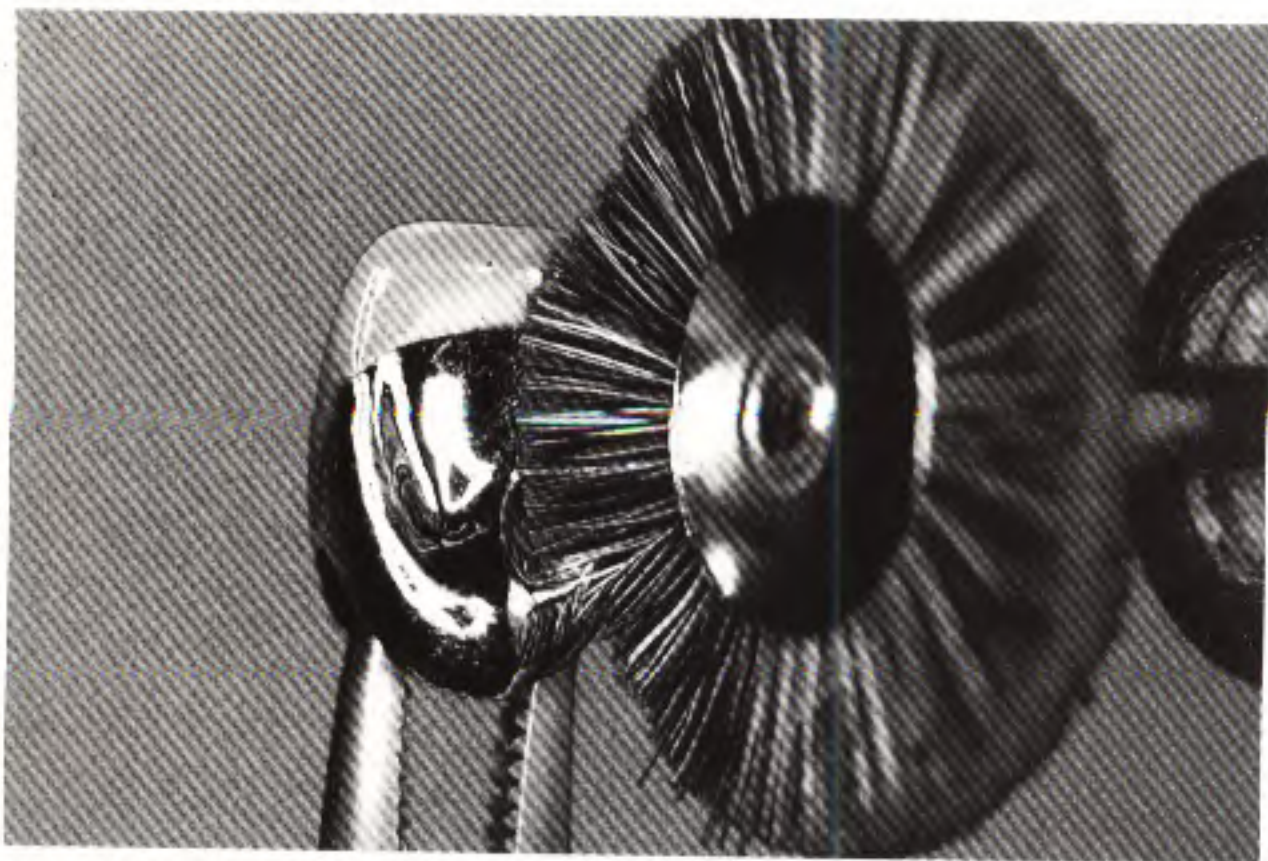
Final polish (Figs 9-60 and 9-61)

Fig 9-60 A final polish is necessary to create a high shine and bring out the brilliant luster of the metal. With a second, soft Robinson brush, pick up a small quantity of rouge. Lightly polish the metal with rouge to establish a high shine.



Fig 9-61 The restoration with a final polish (compare to Fig 9-56). The labial metal collar can be mechanically polished quite adequately with fine green polishing wheels or other fine abrasives (Gold Polishing Kit, Shofu).

Anterior single crown with porcelain lingual surface (Figs 9-62 to 9-64)

This crown is adjusted and contoured using the same materials and techniques described previously. Be-

cause the cingulum was lacking in form and contour, that area should be corrected with a second bake. In preparation for the second body bake, air-abrade the porcelain and steam or ultrasonically clean the restoration.

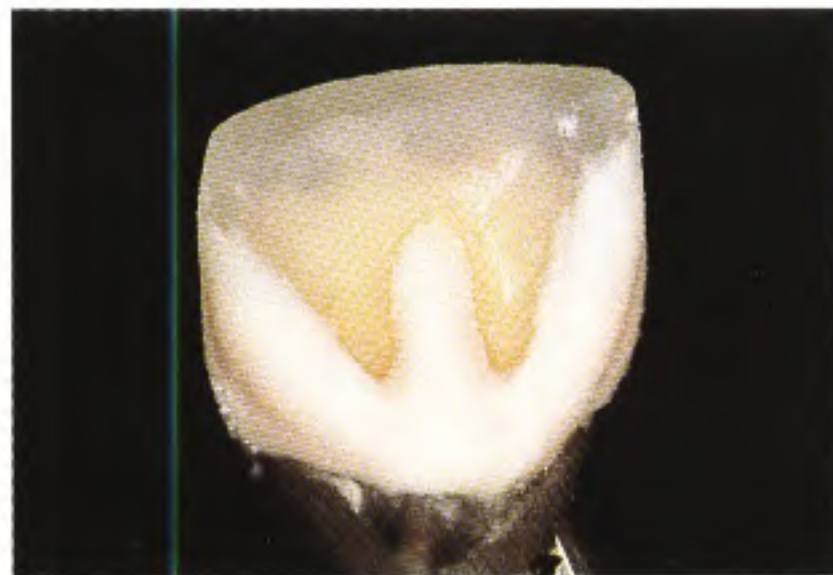


Fig 9-62 Add the appropriate porcelain to those areas needing correction. The second body bake should restore adequate lingual contour and anatomy.



Fig 9-63 Check and adjust the occlusion, then wet the porcelain in stain liquid in preparation for characterization. Characterize (stain) the facial and lingual surfaces as desired.



Fig 9-64 Overpolishing restorations with minimal metal collars can expose opaque porcelain, leave a roughened surface, and permit polishing agents to collect in the surface irregularities. Unless the labial metal collar is fairly wide, be particularly careful if you use polishing compounds in that area; there is always the risk of impregnating the BBC in the porcelain surface. It can be very difficult to remove polishing agents, like BBC, that become embedded in any surface porosities that might exist in the porcelain. Such contamination can result in an unacceptable discoloration of the porcelain.

Posterior single crown with metal occlusal surface (Figs 9-65 and 9-66)



Fig 9-65 After the first porcelain application, the restoration is adjusted and contoured as described previously. Occlusal view of crown with second porcelain application applied and condensed.

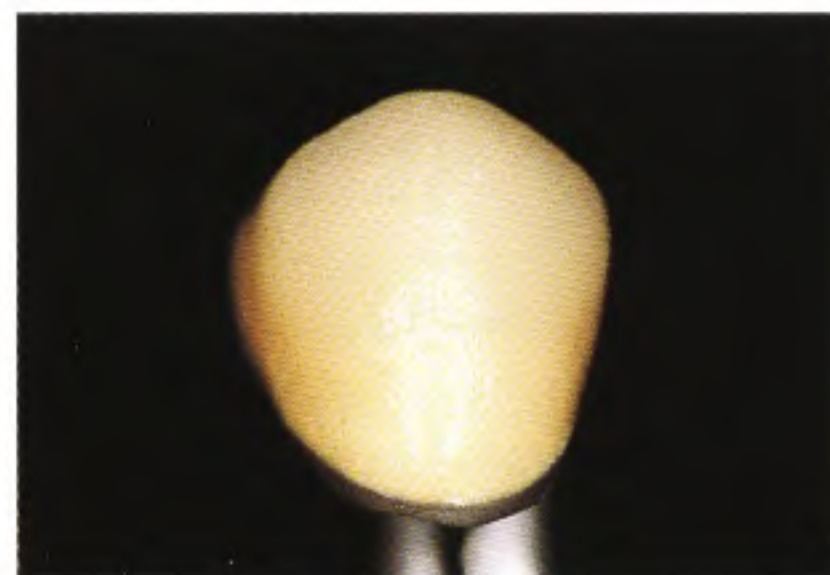


Fig 9-66 Facial view of the crown after the second body bake. The opacous dentin added generally across the cervical region provides a subtle blend of color that transitions well with the middle and incisal one thirds of the crown. The restoration is polished using the materials and techniques described previously.

Posterior single crown with porcelain occlusal surface (Figs 9-67 to 9-70)

Because of the greater bulk of porcelain found with the posterior crown that has a porcelain occlusal

surface, you may observe more porcelain shrinkage. A second porcelain application or even a third firing may be needed to perfect the contours and anatomic form expected of the final restoration.

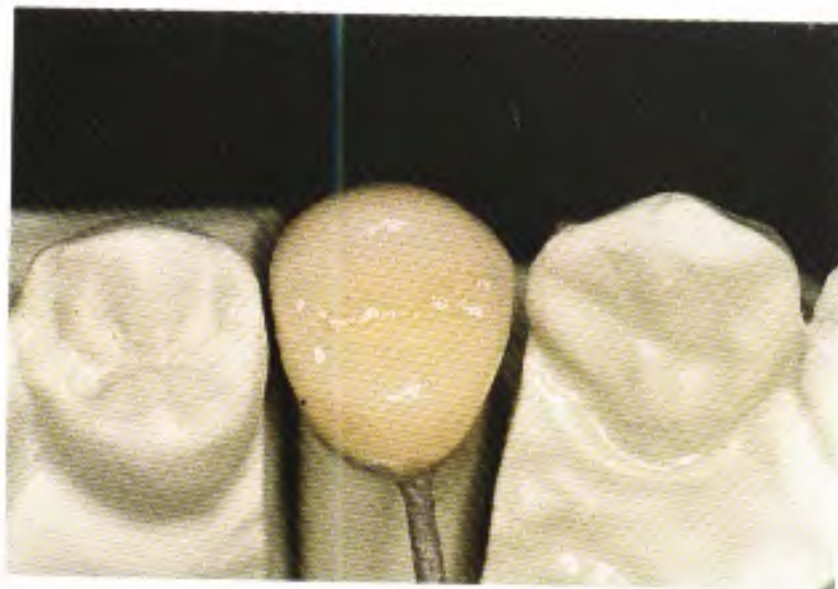


Fig 9-67 An occlusal view of the restoration after the first body bake indicates that the basic anatomical form was retained by the fired porcelain. However, the original estimation of the overall size of the crown (overbuilding 10% to 15%) to compensate for porcelain shrinkage was apparently underestimated.

Adjustment of the porcelain occlusal surface (Figs 9-68 and 9-69)

Depending on your porcelain-building talents, the correction of a crown with a porcelain occlusal surface may require a slight adjustment or be a case of "the occlusal surface must be in there somewhere."

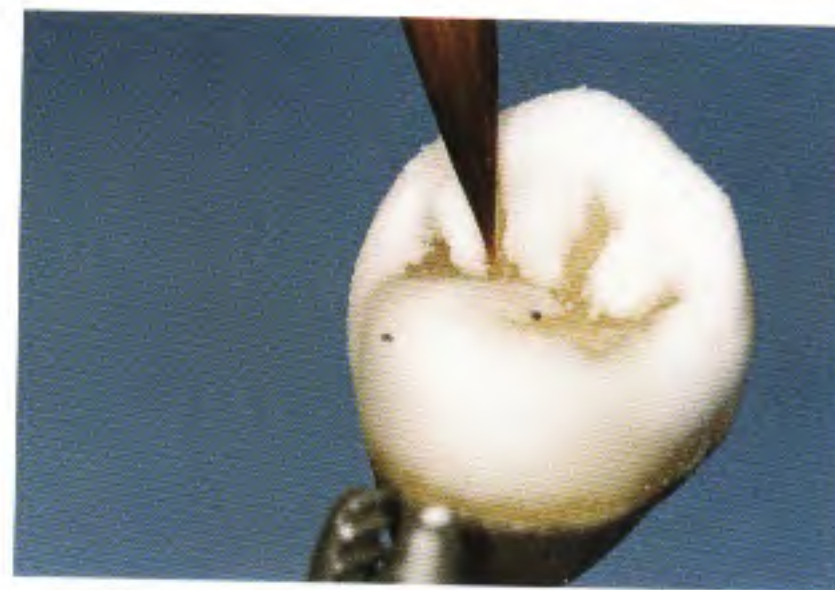
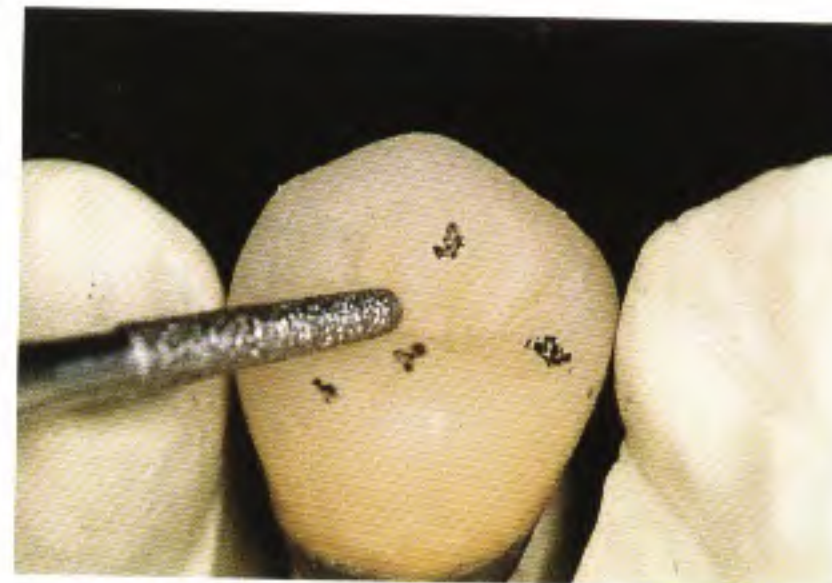


Fig 9-68 Perform any preliminary finishing of the porcelain contours and occlusal surface, then apply the second application of porcelain. Follow the anatomical outline established from the initial buildup.

Fig 9-69 Occlusal view of the crown on the master cast after firing the second application of porcelain. Use articulating film to mark the occlusal contacts and adjust the occlusion and contours according to the occlusal scheme for that patient. For redefining the anatomy, a set of fine diamonds is almost indispensable. If your laboratory is equipped with a high-speed, air-driven handpiece, you will find it extremely helpful for refining anatomical detail. Remember that the best-looking occlusal surface is of no use if you have removed all of the required occlusal contacts.



Staining and glazing (Fig 9-70)

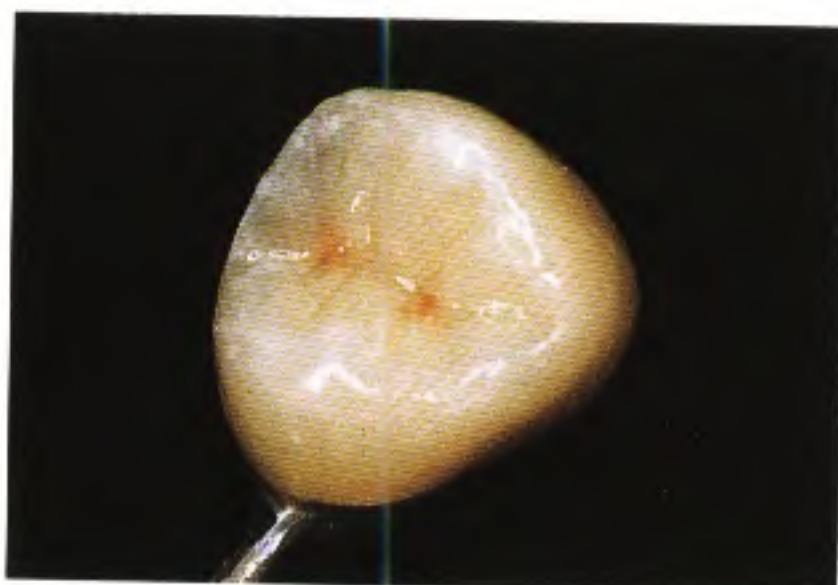


Fig 9-70 Use the same materials and techniques described previously to stain and glaze the facial, occlusal, and interproximal surfaces of this restoration. Occlusal view of the characterized occlusal surface after glazing. Note the use of stains to highlight the occlusal pits and areas of hypocalcification (white), which give a lifelike appearance to the restoration.

The fixed partial denture

(Figs 9-71 to 9-97)

Procedures for the adjustment of a fixed partial denture are similar to those for a single-unit restoration;

however, there are areas that do require additional attention. As previously stated, each retainer must be seated on its individual die.



Fig 9-71 Remove the adjacent stone teeth and the pontic area, and mark and adjust one of the interproximal contacts. Adjust the opposite contact area in the same manner.



Fig 9-72 Replace the pontic area and seat the prosthesis on the master cast. Check the amount of shrinkage on the tissue side of the pontic from the facial and the lingual aspects. Invariably, porcelain firing shrinkage will have created a deficit in this area.

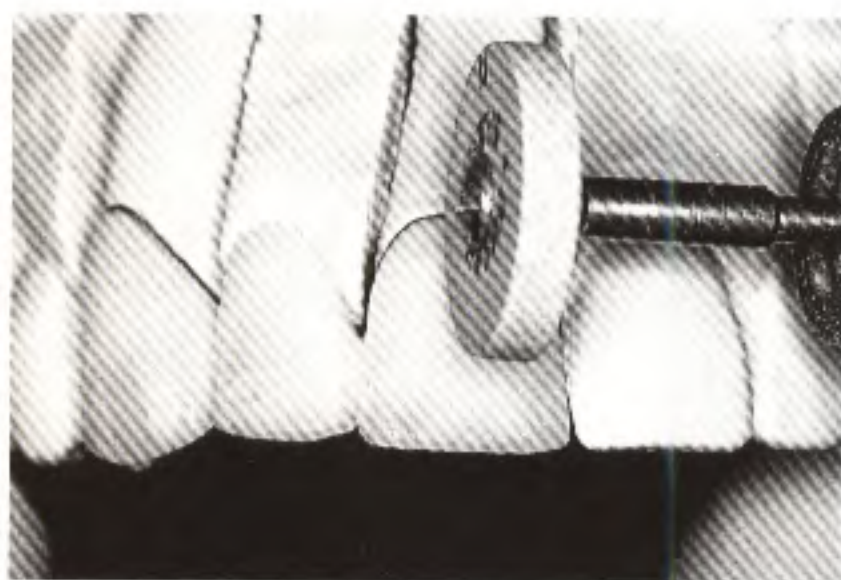


Fig 9-73 Adjust the facial contours using the remaining natural teeth as guides.

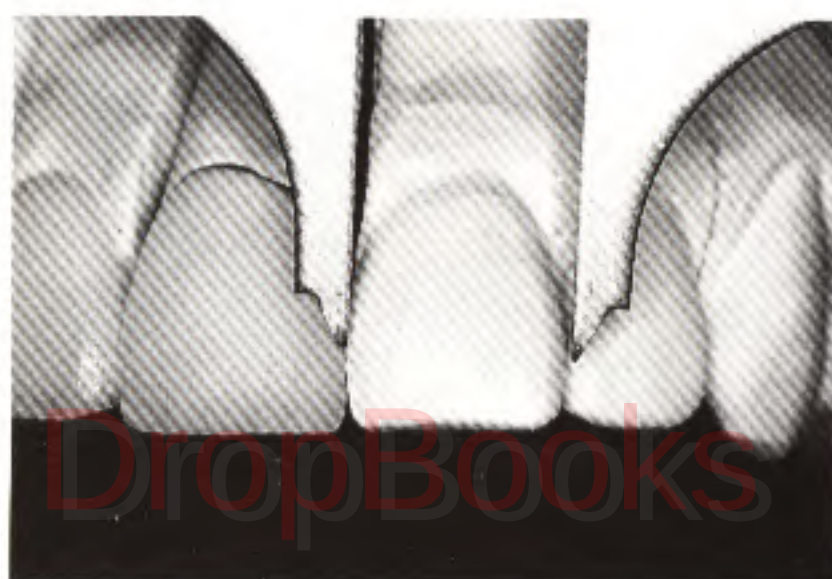


Fig 9-74 Measure the adjacent natural tooth with a Boley gauge.



Fig 9-75 Compare that measurement to the adjacent porcelain surface. Make your measurements of its width and length, because differences of as little as 0.5 mm can be visually detected and should be corrected.

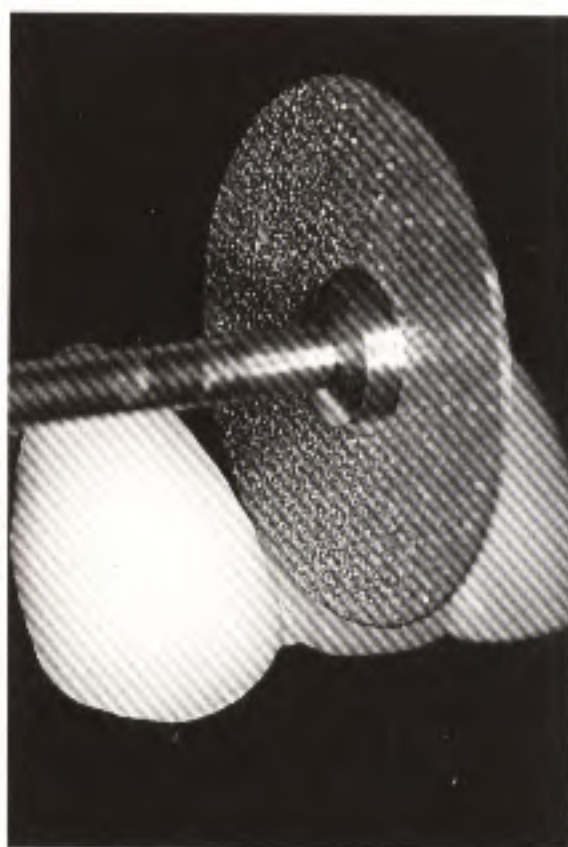


Fig 9-76 Adjust and contour the interproximal areas with a diamond disk.

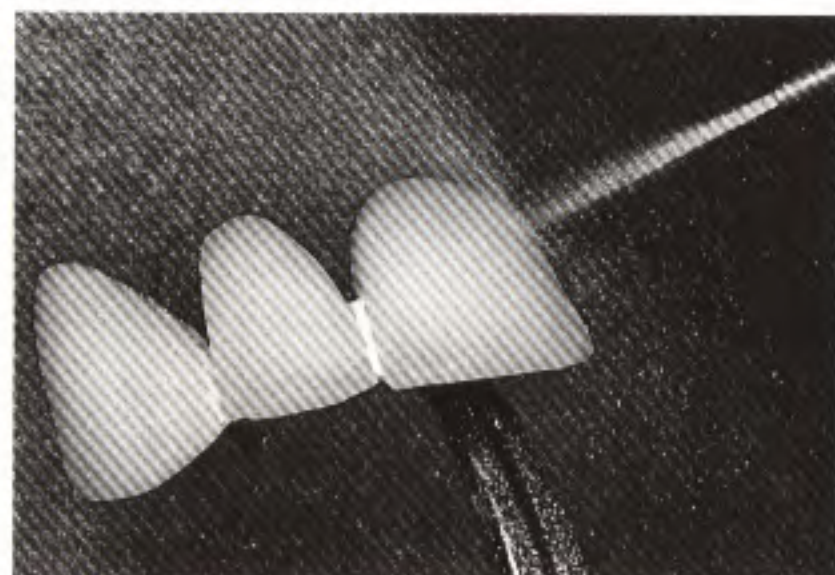


Fig 9-77 Air-abrade the porcelain and then steam clean the prosthesis.

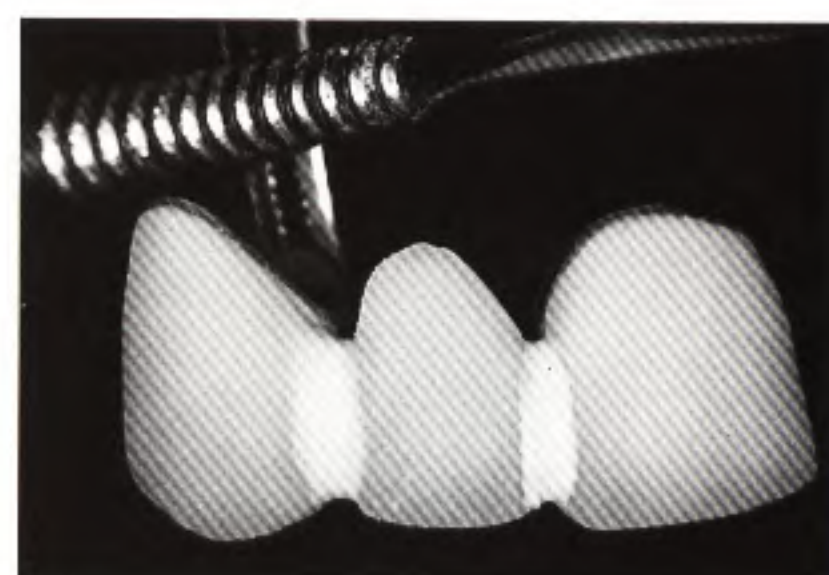


Fig 9-78 Add porcelain to the two connector areas and condense it well.

Fig 9-79 (left) Lightly wet the tissue side of the pontic with distilled water. Add more porcelain as needed until the tissue side is covered completely.

Fig 9-80 (right) Reseat the prosthesis on the master die, after preparing the pontic with moist tissue paper, and condense the porcelain well. While the prosthesis is on the master cast, continue with the placement of the second porcelain application.



Fig 9-81 Facial view of the completed second porcelain application.



Fig 9-82 Facial view of the prosthesis after the second body bake. The deficiencies in the interproximal area between the canine and lateral incisor have been corrected with the second bake.



Fig 9-83 Lingual view of the prosthesis after the second body bake.



Fig 9-84 Next, place articulating film underneath the pontic and mark the porcelain on the tissue side.



Fig 9-85 Adjust the porcelain to conform to your predetermined pontic design.



Fig 9-86 A properly adjusted pontic should be well adapted to the edentulous ridge.

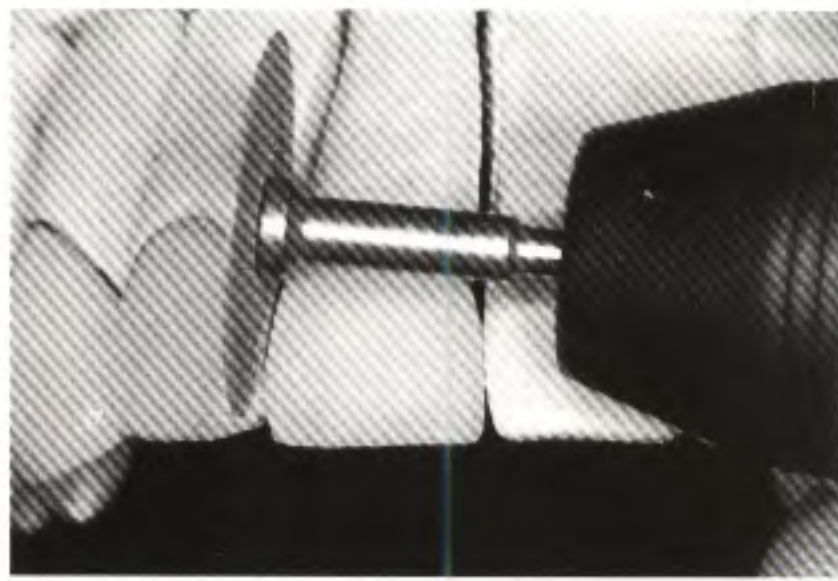


Fig 9-87 Refine the facial contours as needed. Adjust the interproximal line angles with a thin diamond disk, if necessary. Be sure to provide adequate space for the interproximal tissues. But bear in mind that each case is unique and the tendency is to remove too much porcelain in these areas, which creates large, unesthetic open spaces. While interproximal finishing helps to "define" or individualize each tooth, patients generally do not like the appearance created by these large, dark regions that become apparent when the fixed partial denture is inserted in the mouth against the backdrop of a dark oral cavity.

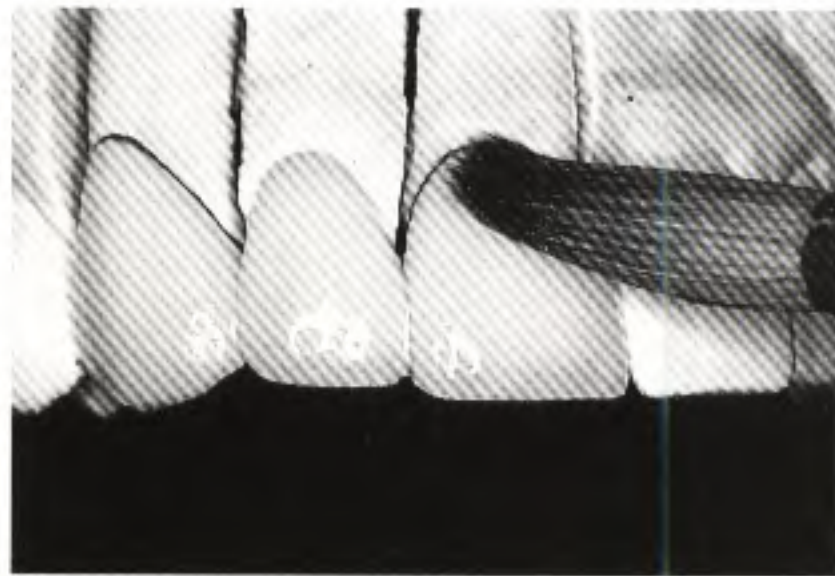


Fig 9-88 (left) After the contouring has been completed, wet the porcelain to assess its esthetics.

Fig 9-89 (right) Add surface texture and go over the facial surfaces with a prepolishing wheel.



Fig 9-90 Facial views of the fixed partial denture after smoothing with the porcelain prepolishing wheel. Air-abrade and clean the prosthesis in preparation for characterization (staining and glazing).

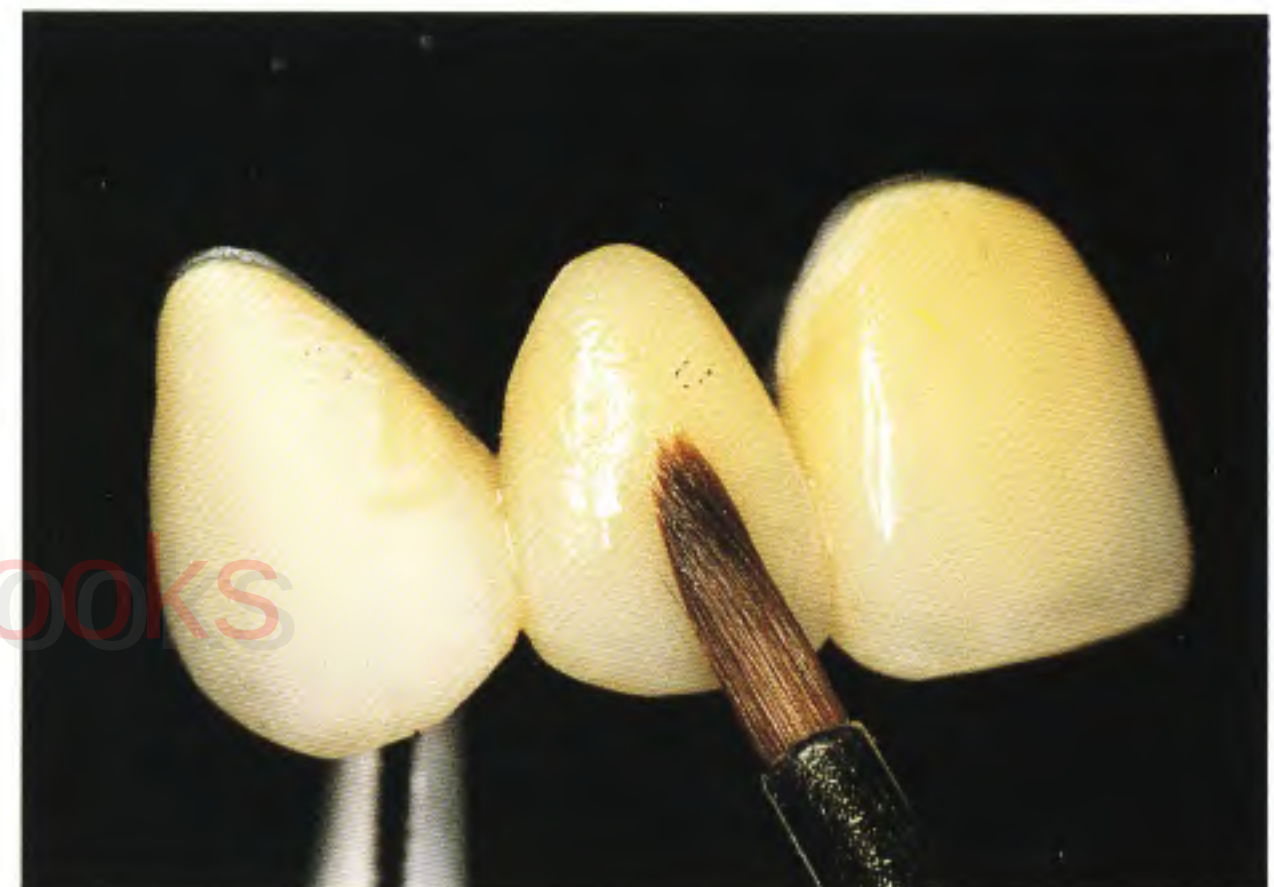


Fig 9-91 Add a small amount of dark brown or gray stain to the connector areas to individualize the teeth. Lightly characterize the lateral and central incisors.

Fig 9-92 Darken the canine more than the incisors. You may add more chroma to the cervical and interproximal areas as the case requires.



Fig 9-93 Continue the characterization onto the lingual surface and tissue side of the pontic.